THE LADDER OF LIFE

THE LADDER OF LIFE

FROM MOLECULE TO MIND

A. Gowans Whyte

THRIFT BOOKS
No. 4

FIRST PUBLISHED 1951

Printed in Great Britain by Richard Clay and Co. Ltd.,
Bungay, Suffolk, and published by C. A. Watts and Co. Ltd.,
5 & 6 Johnson's Court, Fleet Street, London, E.C.4

BIOGRAPHICAL NOTE

A. GOWANS WHYTE, who died as this book was in the press, was a Scot who held varied and highly responsible posts in the fields of journalism, business, and political organization. From his student days at Glasgow University he was keenly interested in science, geology, and biology in particular, and in several books—e.g. *World's Wonder Stories*, *How Life Goes On*, and *Our World and Us*—he developed the theme of Evolution with a concise precision that was matched by the simple charm of his literary style.

CONTENTS

I	*The Dawn of Life*	11
II	*Animals without Nerves*	26
III	*The First Nerves*	39
IV	*The Beginnings of Brain*	52
V	*Following Their Noses*	62
VI	*The Learning Brain*	77
VII	*Nerve in Action*	86
VIII	*The Brain at Work*	91
IX	*The Body–Mind Puzzle*	101

LIST OF ILLUSTRATIONS

FIG.		PAGE
1	*Common Amœba*	27
2	*Amœba Pursuing a Food Particle*	29
3	*Soil Amœba*	31
4	Vorticella, *the Bell Animalcule*	33
5	Stentor, *the Trumpet Animalcule*	33
6	Gonium, *a Sheet of Sixteen Cells*	35
7	Volvox	36
8	Volvox, *a Section of the Body-wall*	36
9	Medusa, *a Jelly-fish*	40
10	Convoluta roscoffensis, *the Green Plant-animal*	42
11	*Earthworm, a Brain Section*	47
12	*Simple Crustacean*	47
13	*Typical Fly*	56
14	*Invertebrate*	57
15	*The Reflex Arc*	58
16	*Typical Nerve Cell*	89
17	*The Human Brain*	92
18	*"Projection Areas" in the Human Brain*	93
19	*Human Electroencephalogram*	104

CHAPTER I

THE DAWN OF LIFE

"THE proper study of mankind," wrote Alexander Pope, "is Man." When he penned this famous line he probably thought that the student of mankind need do no more than he himself had done—observe the men around him, with their virtues and vices, their wisdom and folly. Today we realize that something more is needed. Even those who know little more about Charles Darwin than that he believed in the descent of Man from monkeys—which, in fact, he did not—are aware that in order to understand Man we must take his past into account.

In Pope's time, of course, all that could be learned of the past of mankind lay in history, aided by the teaching of revealed religion, which carried the record back to the creation of the world, of Man, and of all living things about 4000 B.C. Nowadays our time scale for the human story is vastly greater. Darwin's book, *The Descent of Man*, showed that Man and the apes share a common ancestor and that the emergence of the human from the animal form occupied a period of something like a million years.

In no small degree people's minds had been prepared

for so large a draft on the bank of time by advances in the science of geology. Early geologists, whose minds were governed by the Biblical account of the origin of the world, pictured a series of "catastrophies" to account for the features of the earth's crust and the bewildering variety of rocks, some volcanic, some sedimentary, and containing the remains of a multitude of animals and plants now extinct. Opposed to the Catastrophic school there arose—notably with William Hutton (1726–1797) and Sir Charles Lyell (1797–1875)—the Uniformist school, which held that all the facts could be explained by forces of upheaval and denudation still in operation but demanding immense periods of time.

Modern estimates put the age of the earth at several thousand millions of years. But much more than the notion of antiquity emerged from the scientific study of the rocks and their contents. It was found possible to group the rocks in order of age, and thus to arrange the fossils they contain in order of succession.

At first glance the most striking thing about the fossil record might well be the amazing number of forms of life, both plant and animal, that appeared and flourished and then disappeared for ever. When one thinks of the luxuriant vegetation of the Coal Age and the armoured fishes, the dinosaurs, the flying reptiles, and the other curiosities that now serve to adorn our geological museums, one is inclined to think more of "freaks of nature" than of an orderly progression.

Yet there was, over these millions of years, marked by

such a profusion of species that failed to survive, a real progression. In the most ancient rocks the species which have left their mark in fossil form were primitive; only in the later rocks do we find remains of the more highly developed species—the reptiles, the early mammals—which mark the line of advance to the most highly developed of all—Man.

Geology thus suggested the evolution of life. In the place of created patterns of life, each one specially designed and remaining unchanged, it hinted at patterns which were plastic, capable of having developed from simpler patterns and of evolving into more elaborate and highly organized patterns. The story of life on earth was thus conceived to be an unfolding of primitive forms—an unfolding which led to many dead ends, yet did, in the course of many millions of years, culminate in the appearance of Man.

Until the appearance, in 1859, of Darwin's *The Origin of Species*, such a notion of the evolution of life remained little more than a daring speculation. So long as nobody could describe the mechanism by which one species might develop into a different species, the people who believed in fixed species felt secure. Disturbed as they had been by the geological revelation of the antiquity of the earth and multitudes of "wasted" species, they were able to reconcile the scientific and the Biblical accounts by translating the "days" of *Genesis* as æons, and by regarding extinct species as proof of illimitable creative power. Not so readily, however, could they reconcile

themselves to the notion that the development of living things could, like that of the rocks in which the records of life are embedded, be attributed to natural causes which are still in operation.

Echoes of the long and lively controversy over the origin of species still linger in odd corners of the scientific world, but the biologists who cling to belief in special creation rather remind us of the small band of eccentrics who persist in maintaining that the earth is flat. Much has been learned since Darwin's day about the laws of inheritance; the new science of genetics has revealed the process by which genes—the " units of inheritance " —may give rise to " mutations " marking new forms of life which may survive by natural or artificial selection. To the modern biologist the kingdom of life is *one*, and all the manifold varieties of living thing, from micro-organisms to plants and animals and Man, from the extinct forms to the latest products of selective breeding, are parts of a vast, elaborate, and consistent moving picture.

With this conception of perpetual change and unfolding there is no more difficulty in accepting the theory that Man has evolved from more primitive forms of life than in admitting the fact that each individual man begins life as a single microscopic cell which, when it is fertilized, proceeds to divide and grow, divide and grow, until it emerges as a million-celled and highly organized lord of creation. In the course of this development from embryo to Man, there are temporary signs of fish-like and reptile-

like forms through which the human race passed during its pre-human stages of evolution. And each of us carries, in our appendix, in our useless hidden tail, and in our shell-like ears, and other odds and ends, superfluous vestiges of our animal ancestry. Such features are, however, only incidental confirmation of the central truth, derived from a study of living things past and present, that Man is a true child of Nature.

Nevertheless, everybody is not ready to agree that everything concerning life and Man is embraced by natural science. Scientific men may endorse the statement by Dr. W. O. Kermack and Dr. P. Eggleton in *The Stuff We're Made Of* that the belief " in the uniformity of all nature, in the essential consistency of all phenomena, living and non-living alike, is indeed an article of faith which supplies the driving power behind " research into the processes of life. But the ordinary man feels that Man in some respects stands outside the circle of Nature, and also that life itself is a mystery that eludes the test-tube and the microscope. So Nature may be allowed to have its way from the dawn of life to the appearance of *Homo sapiens*—with his unique reasoning powers, to say nothing of his soul. Yet such questions as " How did life begin ? " and " How did Man acquire his spiritual qualities ? " cannot, it is felt, be answered by science. A special creation at the beginning of life on the earth, and another when Man was raised high above the animal, seem to be called for.

The second question, which relates to the highest

rung in the ladder of life, will be discussed later. A few words on the first—and, if anything, more fascinating—question will show how much progress has been made to giving an answer in scientific terms.

Living matter—or protoplasm, to give it its scientific name—is made up of familiar chemical elements, chiefly carbon, nitrogen, hydrogen, and oxygen, with traces of sulphur, phosphorus, iron, calcium, sodium, potassium, chlorine, and some others. Thus it belongs wholly to Nature so far as its materials go. On the other hand, each particle of living matter has a certain very elaborate structure, which is different from the structure of any non-living matter. So we have to ask ourselves whether this structure developed naturally in the course of evolution, or whether it was due to some outside influence—something that, as it were, breathed life into dead matter.

A hundred years or so ago such a question would have been answered, without hesitation, in favour of the "something." The science of chemistry was then rigidly divided into "organic" and "inorganic" with an impassable gulf between the two sections. Every substance produced by a living thing was, of course, classed as organic, and it was thought impossible to produce it artificially. Accustomed as we are nowadays to synthetic dyes and drugs which are identical with those formerly derived from living plants or animals, it is difficult to realize the intensity with which people held the belief that life was life and non-life was non-life and never the

twain shall meet. When, in 1828, a German chemist made urea—which is found in urine—out of " dead " substances, he created a tremendous sensation and marked a new epoch in the history of chemistry. We still, in our schools and text-books, retain the division into organic and inorganic, but it is mainly a matter of convenience; organic chemistry has become simply the chemistry of the carbon compounds.

As success followed success in the art of synthetic chemistry, interest in the problem of the origin of life itself was greatly stimulated. Since we had learned how to manufacture, out of the non-living, so many compounds previously obtained only from the living, what was there to prevent our manufacturing the living molecule itself? So ran the argument that inspired a number of optimistic experimenters in what was known, at the turn of last century, as "spontaneous generation." Concoctions thought to be suitable were sterilized and incubated under a variety of conditions of temperature and pressure in the hope that they would emerge as protoplasm.

A few successes were claimed, but they convinced few people apart from the experimenters themselves. All these researches had a fatal flaw; it was impossible to be sure that the brew was completely sterilized. Nothing was known then about the viruses—those lowly organisms which are so minute that they slip through filters fine enough to catch bacteria. But even if the experiments had been made from an absolutely " dead line," they were

hardly likely to succeed. The period at which life appeared on the earth is estimated to be several hundreds of millions of years ago. Almost certainly it originated in water, but we can do no more than speculate on the chemical substances present in the water, on its temperature, and on other conditions at the critical time. As there is no sign of life having been "spontaneously generated" at any later stage in the evolution of the earth, the synthesis of the living molecule seems to depend on reproducing the precise conditions existing at the one and only (so far as our world is concerned) dawn of life. Moreover, there are good reasons for believing that the synthesis, like so many important events in the history of life, took an extremely long time.

Thus we are almost forced to admit that the question of the origin of life remains an open one. Nevertheless, the trend of scientific thought is definitely, and increasingly, towards an answer in scientific terms. This may seem to be a case of wishful thinking, and in a sense it is so. If the scientist who is studying the behaviour of living tissue by chemical analysis and by microscopic examination of its physical structure and behaviour has to take into account some mysterious "life force" or "vital principle" he is rendered helpless. How is he to know whether what he observes belongs to chemistry and physics, or to the realm of creation? Are all his researches to be governed by an unknown quantity?

Biochemistry is the study of living processes; it is a comparatively new branch of science, but it has made very

rapid progress and achieved remarkable results. And the claim has been made for it that, in all its numerous observations of living organisms and tissues of every variety and under every kind of condition, and in the mechanical, electrical, and chemical facts it has accumulated about life in action, no case has been noted where the ordinary laws of physics and chemistry could be held not to apply.

In one branch of biochemistry—the study of the minutest forms of life—the facts gathered have had a curious influence on the problem of the origin of life. One of the difficulties formerly felt in believing in the natural origin of life was that the simplest known forms of life were not just single living molecules, but highly organized systems of molecules of various kinds. It was rather a tall order to be asked to believe that complex organisms with an elaborate structure represented the first stage in the natural evolution of life. However, with the discovery of bacteria, and still more of viruses, the difficulty was minimized. Bacterial rods or spheres under the ordinary microscope appear to have little or no structure, but under the electron microscope, which magnifies 100,000 times and enables us to see the actual molecules, structure does become visible, and is seen to be —although very complex compared with inorganic molecules—much simpler than that of a one-cell organism like the amœba, which we shall describe in the next chapter.

Some bacteria, by the way, have thin, whip-like tails

(called *flagella*), which they lash about and with which they are believed to swim. In their molecular structure, these flagella show the same basic design as hairs and muscle-fibres in animals—an interesting sidelight on the unity of Nature.

Viruses, which are the cause of colds, influenza, and many other diseases, are so small as to be quite invisible under the ordinary microscope; so small, also, that they pass through the finest of mechanical filters—a fact which accounts for their escaping notice so long. Like bacteria and also the amœba and other single-celled animals, they multiply by dividing into two; they are thus entitled to be regarded as living. Unlike bacteria, however, they cannot feed and grow and multiply on ordinary food; they must draw their nourishment from living tissues. In a word, they are parasites, not independent organisms. One of the best-known is the virus that feeds on tobacco leaves and causes what is called "mosaic disease," from the spotted appearance of the leaves.

This and other viruses have been obtained in a crystalline form—a fact which is of the greatest interest. Previous to this discovery the tendency to form crystals was known only among chemically pure *non-living* substances; it served, indeed, as a means of distinguishing animate from inanimate things. Thus the viruses seem to be in a no-man's land between the living and the non-living. By their ability to take crystal shapes they belong to the non-living; by their ability to absorb food and multiply

they belong to the living. Some authorities suggest that viruses were not always parasites, but, after living independent lives, found it easier to live on other organisms. In other words, they have degenerated. However this may be, we shall find other proofs that traffic on the ladder of life can go down as well as up.

It would be too much to say that the viruses have bridged the gulf between the two kingdoms into which the world of Nature has been divided. But at least they serve to narrow the gap. It is worth remembering, too, that the discovery of these frontier forms of life is comparatively recent, and that further discoveries may be looked for as our methods and instruments of research improve. As things are, however, we have learned a great deal about the architecture of organic substances. The chemist can, for example, take some compound produced in a living organism and find out not merely its chemical composition but also the structural arrangement of its molecules. Since it is on this arrangement that the behaviour of the compound depends—just as the action of a machine depends on its design—the chemist can then proceed to fabricate a substance with the same molecular pattern. Such is the technique used in the making of synthetic products.

So the biochemist does not trouble his head about unknown quantities or mysterious life-forces. He aims at relating what goes on in living things to chemical action between substances with certain known structures.

Progress in other branches of science has helped to

accustom our minds to accept "life" quite simply as the behaviour of substances with a particular chemical structure. At the time when men were most exercised over the problem of the origin of life, the prevailing idea of matter was that, in the last resort, it was made up of atoms—minute particles which could not be divided. The chief property attributed to atoms was the power of combining with other atoms to form chemical compounds; in addition, they were subject to certain forces —the force of gravity, of electricity, and so on. Into this picture the notion of a life-force energizing matter into unique combinations fitted only too easily.

But when physicists discovered electrons and protons, the atom was seen to be a complex system packed with energy. Today we do not need to be reminded of the intensity of the energies locked in the atom, and we are much more ready than our forebears to accept the famous saying of Professor Tyndall at the Belfast meeting of the British Association in 1874: "We see in matter, hitherto covered with opprobrium, the promise and potency of every form and quality of life." When a mere speck of matter resolves itself into an aggregate of atoms with an inconceivably vast total of particles in perpetual motion, there seems indeed no limit to the possibilities of still more complex combinations.

Turning from the infinitely little to the infinitely great, we find another change of outlook bearing upon the problem of the place that life occupies in the evolutionary picture. Towards the end of the nineteenth century there

was a good deal of discussion about the possible existence of life on the planet Mars. That question is still open, but the general verdict would seem to be in the negative. Later, when the increasing power of telescopes aided the exploration of the stellar universe, the question took a new and more speculative form: what were the odds among the starry systems in favour of the existence of planets on which the conditions of temperature, atmosphere, and so on could make life as we know it possible?

For a time the astronomers inclined to the belief that the chances of life existing anywhere in the distant regions of space were negligible. On this view our earth might be unique—the sole sphere, among countless multitudes, on which life had appeared or could appear. Such a conclusion must, of course, have a strong effect on our ideas of the nature and purpose of life. However, with the advance of astrophysics, which has so greatly enlarged our knowledge of the constitution of the stellar universe, expert opinion began to change. The probabilities, it now appeared, were that in numerous instances the conditions suitable for life have come, or would come, into existence.

Into the higher mathematics of this controversy there is no need for us to attempt to enter. The most interesting feature about it from our point of view is that when the dramatic alteration in the betting took place, everybody concerned seemed to take for granted that wherever and whenever the conditions were suitable, life would duly make its appearance and proceed to evolve

very much as it has done on our globe. Nobody, in short, suggested that life in any part of the universe might be anything but a matter of natural cause and effect.

On that basis we may proceed to tell a part of the story of the evolution of life which, although as important as it is fascinating, has been rather neglected in books on biology written for the general public. Most "nature books" describe the form, appearance, and habits of living things; when they deal with the higher animals they revel in accounts of wonderful instincts and intelligent behaviour. Rarely do they touch on the mechanism which determines the habits or controls the behaviour of the animals they describe. Still more rarely do they give any hint of the relationships between different sorts of animals, which show, incidentally, that the lower animals have a simple system of control while the higher animals have more and more elaborate systems of control. At the top of the tree of life stands, of course, Man himself, with the most elaborate system of all.

What we are setting out to do is, in fact, to trace the growth of something which starts with being as unconscious as the action of a flower in turning towards the sun, and gradually develops until it becomes the conscious control that marks what we call "intelligence" and "mind." Each one of us, in our individual life, goes through these stages from the unconscious to the conscious; Man, in evolving from the animal through the millions and millions of years of geological time, travelled a similar road. If, therefore, we seek some light upon

the age-long "mystery of mind," we may well find it through trying to trace the way in which a mind capable of memory, of reasoning, and all the rest of it, arose out of simpler systems of control in the animal ancestors of Man.

CHAPTER II

ANIMALS WITHOUT NERVES

MANY biologists have made the acquaintance of the amœba in their earliest student days. *Amœba proteus* (to give this tiny one-celled animal its official name) is very well adapted to the study of life in its elementary form. Commonly found in stagnant water, it is in ample supply. Live specimens can be readily observed and experimented on under a microscope. Their life-histories can be compiled, and they are seen to include all the essential operations that make up what we call life.

As we have learned, the boundary between the living and the non-living is not now considered to be hard-and-fast. There is great difficulty in framing a short definition of life that separates it from non-life. But it will serve our purpose to show in detail how the amœba illustrates the A.B.C. of life.

In the first place, the amœba is *irritable.* Here the word is used not to indicate bad temper, but merely to describe the fact that the amœba is sensitive to touch, or the nearness of food, or some other influence. Irritability is a rather old-fashioned word for the phrase " response to stimulus."

The amœba also *grows* by taking in food, digesting it, and excreting the waste material. It *breathes*, by taking in the oxygen dissolved in the surrounding water and expelling carbon dioxide, just as we do with our lungs. And it *reproduces* itself, by the simple process of dividing into two when it has reached a certain stage of growth. Thus it contrives to keep itself going as an individual amœba and also to maintain the race of amœbæ.

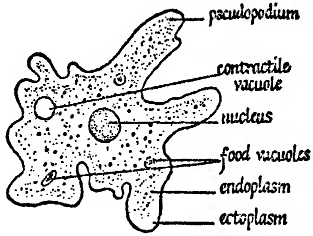


FIG. 1.—A common amœba, enlarged from a diameter of about 1/100th of an inch.

At one time it was thought that the amœba was a simple blob of living matter, with no difference between one part and another. We now know that, although it is a single cell, it has—in common with all living cells—quite an elaborate internal structure. The outside layer is like a thin, transparent skin, enclosing body material which, containing numerous granules, is not transparent. Actually, there seems to be a constant interchange between the clear and not so clear substances, as if the outside layer were clarified by contact with the water in which the amœba lives. Nevertheless, biologists dis-

tinguish between the two, calling the outside layer *ectoplasm* and the living substance inside *endoplasm*; the first is rather fluid, and the second like a firm jelly.

The most striking and important feature inside the amœba is the *nucleus*, which divides into two when the amœba "multiplies." Each amœba produces two amœbæ complete with nucleus and identical with itself. This operation takes place when the amœba has grown to the stage where the mass of endoplasm to be fed is greater than can be supplied through the surface. By splitting, the overgrown amœba converts itself into two with a much higher proportion of area to mass.

Another feature is the *vacuole*, a compartment which plays a part in the excretion of material taken in with food; it is seen to swell and sometimes to burst, discharging its contents. Fragments of food can also be seen dotted about the endoplasm.

We are not, however, concerned so much with the amœba's digestion as with its behaviour. In this connection its most notable feature is the continual change of shape, as is indicated by the word *proteus*. (There are, by the way, many forms of amœba in addition to the protean, which is so familiar that it is usually understood when anybody speaks of "the amœba.") Portions of the amœba's body are thrust out; they often appear so like feet that they have received the name *pseudopodia*, or "false feet." In fact, they are used for the usual purpose of feet, enabling the amœba to move along in pursuit of food or away from danger.

The thrusting action comes from the endoplasm, which is always in a state of restless agitation. It enables the amœba to keep moving in the search for food and to engulf any grain of nourishment. It also serves to demonstrate what is meant by "response to stimulus." When an amœba is pricked with a needle, the part that is touched shrinks away and the opposite side thrusts out false feet in an effort to escape. If the experiment is

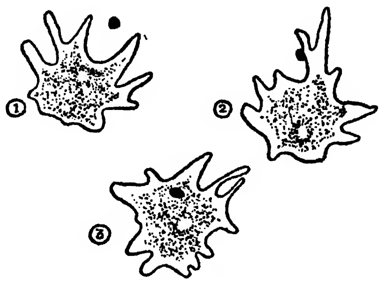


FIG. 2.—An amœba pursuing and ultimately absorbing a food particle (small black spot).

made when the amœba is already on the move, and the needle is applied at the leading end, the reaction is particularly strong. The endoplasm moves quickly from the affected region, causing the middle of the body to bulge and push out the pseudopodia on the far side; whereupon the amœba moves on.

Much the same sort of thing happens when we are pricked with a needle. We automatically draw back and move away, and we do this all the more vigorously if the limb that is pricked happens to be moving against the

needle at the critical moment. There is, however, a vast difference in the two mechanisms of "response to stimulus." We have an elaborate system of nerves, carrying messages (of pain, for example) to nerve-centres which send out "action messages," as it were, to the muscles of the affected limb. But the amœba has no nerves, no sense-organs such as eyes, ears, or nose. Whatever impulses, mechanical or chemical, come to it from outside have to be handled by the protoplasm of its little body.

We realize, then, that protoplasm is itself sensitive, and that when it is excited the disturbance travels on and produces a response, such as the engulfing of a food-particle or a retreat from danger. What kind of disturbance it is we cannot say for certain, but it appears to be partly chemical and partly electrical. What we are certain about is that the protoplasm of the amœba *is* affected by a stimulus, such as the prick of a needle, and that the change is passed on, and causes the animal to adjust itself to the stimulus by movement. In other words, the complex business of receiving a stimulus, passing it on, making an adjustment, and taking action—a business involving, in the higher animals, a series of special nerves and nerve-centres and muscles—is handled by simple protoplasm. Moreover, the same protoplasm looks after feeding, digesting, excreting, and breathing. It is, so to speak, an all-in-one living machine.

Before leaving the amœba and going on to discover how the machinery of control became step by step more

complex and more efficient, we may note that the amœba is probably one of the oldest species in the world. Although we trace the development of life from the amœba stage up to Man himself, there has been more than evolution in the story. Some species have gone downward instead of upward. Many have disappeared. What makes for survival in all cases is whether the species is suited to the conditions under which it lives. Should the conditions change and the species be unable to adapt itself to the change, it dies out.

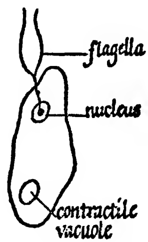


FIG. 3.—A soil amœba, with two whip-like flagella which help it to move.

The amœba lives in a very simple world. Given water with organic matter in it, it might live for ever. And as it multiplies by dividing into two amœbæ, it never changes. Even were the water in which it swims to dry up for a while, all would not be lost. During drought the amœba's skin becomes tough and retains the internal moisture until the rains come again. It can also do without an outside supply of oxygen for a period.

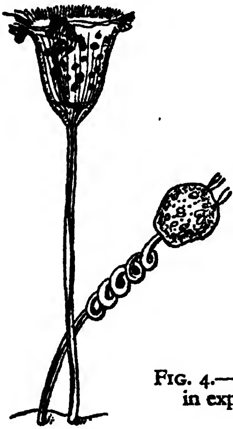
Small wonder, therefore, that this plastic "blob of protoplasm" has a pedigree stretching back for millions of years.

The next step up the ladder of life seems to be the appearance of a kind of "fore-and-aft" arrangement. *Amœba proteus* has no head, no tail; in its changes of shape one part of its body serves as well as any other. But a near relation—an amœba living in the soil—sometimes passes from the ever-changing form to a stable form, like a fat sausage with a firm skin. At one end, two whip-like flagella, similar to those on certain bacteria, stretch outward and help the amœba to move. At the root of the flagella there is a bunch of threads and granules, which controls the movement of the flagella.

Here we have an early case of one part of the protoplasm becoming different from the rest and acting as a special organ of control. The pattern is a very simple one, but it *is* a pattern. In other one-cell animals the pattern becomes a little more elaborate. The "bell animalcule" (*animalcule*, tiny animal), for example, has a long, thin stalk fixed at one end to a water-plant and expanding into a bell-shape at the other end. Round the edge of the bell are a lot of thin threads that vibrate, sweeping food particles into the bell, where there is a mouth and a stomach. The protoplasm round the edge is more sensitive and more active than it is elsewhere. If anything harmful touches or comes near the edge of the bell, the bell curls inwards, forming a kind of ball. If the irritation continues, the stalk shrinks into a corkscrew

shape, drawing the bell away from the source of disturbance.

In the bell animalcules, therefore, we have a structure that is like a head controlling a long body. As the shrinking of the stalk comes later than the shrinking of the bell, it is clear that the controlling impulse takes some time to travel down the stalk. Experiments show that it



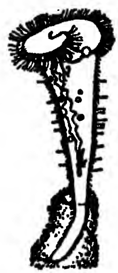


FIG. 5.—*Stentor*, the trumpet animalcule.

FIG. 4.—*Vorticella*, the bell animalcule, in expanded and contracted form.

gradually loses power on the way. In other words, protoplasm is a slow conductor of impulses—a point that will be mentioned again when we come to deal with the action of nerves.

Somewhat similar to the bell animalcule is the "Stentor" or trumpet animalcule, with a stalk that gradually widens to an opening fringed with active threads. The Stentor can attach itself to a fixed base by the end of its

stalk, and can sway in the water to catch food particles (which are swept into the trumpet by the waving threads), and also to avoid trouble. When a shower of microscopic dust was allowed to fall on a Stentor, the animalcule bent a little to one side to escape the nuisance. Next it tried to sweep the dust away from the trumpet mouth by putting the waving threads in reverse. As the dust went on falling, the Stentor curled up in the same way as the bell animalcule. When it opened up again and encountered the dust, it finally detached itself and swam away.

In thus appearing to try one trick after another, the Stentor gave a good imitation of intelligent behaviour. Actually, of course, it was doing no more than showing the "irritability" of living matter of the humblest type —far too humble for us to speak of conscious action, to say nothing of intelligent action. We shall later describe other simple organisms which lead lives so elaborate that they suggest something more than mere physical and chemical action. It is very tempting to try to account for animal behaviour by endowing animals with greater powers of thought and feeling than they really possess. Scientific men are always on their guard against this temptation, and choose the simplest explanation that will meet the case.

There are thousands and thousands of different patterns among one-cell animals, but very few of them are of more than microscopic size. As we have seen from the amœba, which splits in two when it reaches a certain

stage of growth, there is a limit to the size of organisms of this type. Only by joining many cells together can larger organisms be produced. And as a quite simple many-cell animal like the "wheel animalcule" has a thousand or so cells, and the common earthworm has millions, we can understand what an important step in evolution was taken when the change from one cell to many cells occurred.

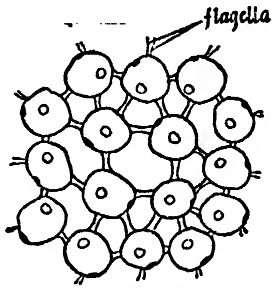


FIG. 6.—*Gonium*, a sheet of 16 cells, each of which has two flagella.

A more humble example of a many-cell organism is the *Gonium*, a flat, oval sheet of sixteen cells joined together with strands of protoplasm. Each cell has two flagella, and the lashing of these flagella drives the colony through the water. It is probable that the strands of protoplasm do more than merely hold the cells together; they may well conduct impulses from cell to cell, so that the group is organized as one animal.

A less humble example is the *Volvox*, a small, pin-head sphere which contains anything up to ten thousand or more cells, all alike and each carrying two flagella. The

cells form a single layer round a central cavity and, as in the case of Gonium, they are connected by a thread of protoplasm. Since the flagella all over the body move

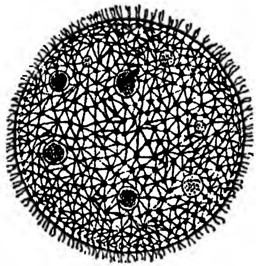


FIG. 7.—*Volvox*: the cellular sphere is magnified about 100 times.

in harmony, like the rowers in a boat, to propel the sphere in a certain direction, Volvox acts more like a single animal than a mere colony of animals. Never-

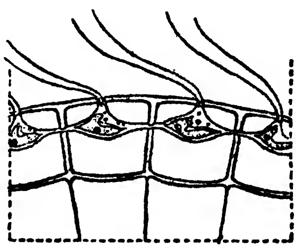


FIG. 8.—*Volvox*: a section of the body-wall, greatly enlarged to show the flagella.

theless, it is difficult to draw the line between the two. Gonium and Volvox are interesting to us because they are stepping-stones from the one-cell animal to the many-

cell animal, which is a real individual. By a real individual we do not usually mean a bundle of cells, all exactly alike, but a collection of different kinds of cells, each kind with its special work to do, but doing it in co-operation with the others.

We think, in a word, of muscles, lungs, heart, eyes, digestive organs, and so on, arranged in a certain pattern and acting together. This acting together requires some system of quick communication among the various parts, as when an empty stomach signals to eyes and muscles to get busy with the search and capture of food. This system is provided by nerves and, in the higher animals, by the brain.

For our next step up the ladder we must, therefore, look for the appearance of nerves to knit together and control the actions of the various parts of an organism.

When an organism is very tiny, it has no need of nerves. Although protoplasm is not a very good conductor of impulses, the distance that the impulses have to travel is so minute that a bad conductor serves well enough. Thus the stimulus given by a needle touching an amœba seeps through the protoplasm to the nucleus—a microscopic distance—in "next to no time." In a larger organism the seeping action would take an appreciable time to bring the required response to stimulus, unless a more rapid system of communication were provided. We may, therefore, look upon a nerve as a road made through a jungle, or a telephone-line laid to carry messages at speed.

In some small, many-cell animals there are signs that certain parts carry the impulses; these are like faint cross-country tracks rather than roads, and they may be described as the forerunners of the special nerve fibres that carry impulses at the rate of 100 feet per second.

CHAPTER III

THE FIRST NERVES

It is not easy to lay one's finger on the exact stage in evolution when nerves begin to appear. From the behaviour of Volvox, where all the flagella keep time, it would seem that the cells are connected by some tissue that carries messages more quickly than ordinary protoplasm. There is, however, no clear indication of such special channels of communication.

In the common sponge we have another hint of an early form of nerve. A sponge is a mass of tiny cavities, the whole being shaped something like a wine-jar with a narrow opening. Water is taken in from the pores all round the jar and expelled through the opening. At certain times the opening is closed, and this action is performed by a ring of muscle at the opening. Some biologists think that the muscle is not a mere muscle, but is, like a nerve, specially sensitive to a touch or other stimulus. It is as if the "division of labour" between nerve and muscle that we see in higher animals has not begun, one tissue taking on both jobs.

In the familiar sea anemone, which fastens itself to a rock and sweeps food into itself by the waving tentacles, we find sensitive cells on the surface with thread-like

ends that reach down to muscle cells. Here there is definite division of labour. Each little set of nerve and muscle is, however, quite separate. When a tentacle is cut off and touched with a piece of food it curls up just as it would if it were still part of the body, thus showing that the nerve-muscle action is local, not centralized.

For a simple nervous system that knits all parts of an animal together, making it act like a unit, we must turn to the jelly-fish. Its umbrella-shaped body has long,

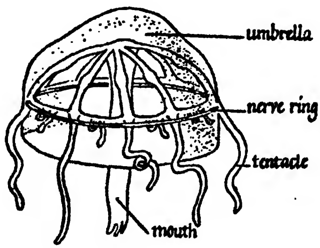


FIG. 9.—*Medusa* : a jelly-fish with a " nerve ring " inside the umbrella.

sensitive (and sometimes stinging) tentacles dangling from its rim; as it swims along, by contracting and expanding the umbrella, the tentacles sweep food into the mouth, at the end of the " stick " of the umbrella. The beautiful swimming movement is effected by muscle cells on the under side of the umbrella and controlled by a " nerve ring " inside the edge of the umbrella. Connected with the nerve ring is a network of nerves spreading through the body to muscles and tentacles.

A similar arrangement is found in the starfish, where

there is a nerve ring at the centre with nerve cords down the middle of each ray to the tip. In neither case, however, is there full central control. A cut-off tentacle of the jellyfish will behave as if it were still connected to the ring, and the starfish is very loosely organized. The next advance, in fact, appears in animals of a different type—those which have a head that dominates the rest of the body.

Before we pass on to this group it will be useful to describe the behaviour of a marine "worm," which occupies a very humble place in the worm family. Unlike the common earthworm, which is made up of a series of rings, it is a one-piece organism, one-eighth of an inch long and one-sixteenth of an inch wide, and, as it is coloured green, it looks like a thin fragment of a leaf. Its body is covered with fine threads, by means of which it swims. Near the head it has two eye-spots, and between them is a hollow sphere—the *otocyst*—with a minute lump of chalk inside it. (The purpose of the otocyst will be described presently.) About midway, but a little nearer the head, lies the mouth, connecting through a gullet with food vacuoles like those in the amœba; undigested food may be discharged at any part of the body. There is no heart, and there are no definite muscles and nerves. Finally, it does not reproduce by dividing, but by laying eggs, each animal having both male and female organs.

Such is *Convoluta roscoffensis*, which swarms by the million on the beaches at certain parts of Normandy and

Brittany, and, from all accounts, nowhere else. Its habits were very closely studied by the late Sir Frederick Keeble, and recorded in his little book called *Plant Animals*.

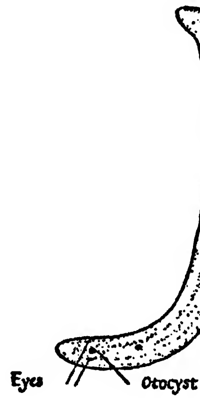


FIG. 10.—*Convoluta roscoffensis*, the Green Plant-animal.

Colonies of Convolutas are visible on the sands at low tide, forming streaks and patches of dark green. The patches are larger during spring tides and smaller during neap tides. When the sun is shining brightly, the worms lie motionless; on dull days they are continually gliding to and fro. At such times a heavy footfall will make them vanish rapidly into the sand. At night they remain below, but when the moon is shining a number may be seen by the light of a lantern.

As the tide rises, the shock of the waves drives the Convolutas into the sand, where they are safe. When the

tide falls and the sand appears, they rise again—if, of course, the sun is shining. By this up-and-down movement they get all the light possible during low-water periods. So swift is the movement that a moment after the falling tide has exposed the site of a colony a faint green shade becomes visible; before the waves have receded a few yards the patch is dark green.

Another rhythm governs the process of egg-laying. "A colony of *C. roscoffensis*," wrote Sir Frederick Keeble, "is indeed a well-drilled army. Not only do all its members take cover as one unit at a given signal, not only do the individuals keep their ranks when the order comes to climb to the surface once again, but they are born together, grow up together, mature at the same time and lay their eggs simultaneously." Egg-laying begins with the onset of the spring tides; it goes on for a week or more and then, with the arrival of the neap tides, it stops, even though some of the animals are still carrying ripe eggs.

This brief account suggests that *C. roscoffensis* is a very clever little animal, capable of choosing this or that line of conduct to suit its own ends. However, when it is taken into the laboratory and experimented on, its behaviour can be explained by simple reactions to certain forces, notably gravity and light.

Sensitiveness to gravity is connected with the curious otocyst, which is like a piece of ballast that keeps the animal upright and also makes the pull of gravity effective. If the animal changes its position in relation to the

pull, the piece of chalk rolls on the sensitive wall of the otocyst and induces a movement of the body. When samples of Convoluta larvæ are placed in water in a glass tube, and the tube is shaken slightly, most of the animals drop down, some tumbling, some curvetting. But a few may remain glued to the side of the tube, and they can be dislodged only with difficulty. Examined under the microscope, these stickers are found to lack properly developed otocysts.

But if the pull of gravity accounts for the sinking of Convolutas, what accounts for their rising? Once more the answer is found in the laboratory. As Sir Frederick Keeble wrote:—"Brought into the laboratory and placed in sea-water in a glass vessel near the window, *C. roscoffensis* behaves precisely like the leaf of the geranium in the cottage window. Each animal turns to the light, moves towards it and finally exposes the surface of its body athwart the line of light. Within a minute or two the reaction is completed. Swiftly and, as it would seem, inevitably the animals assemble on the side of the vessel toward the light, and form a green scum on the surface of the water. If the vessel is turned round, the animals release their holds and, either falling like a precipitate to the bottom or edging round the side of the vessel, arrive once again at the water's edge on the side of the vessel directed toward the light."

An interesting detail is that experiments with coloured light show that the Convoluta is attracted only by the green or white light. The sensitiveness to green light is

probably due to the fact that the eye-spots are orange-coloured—thus absorbing green light.

Another experiment disclosed an action that at first sight seemed very mysterious. When a batch of *C. roscoffensis* is scooped up with sand and water in a cup and taken into the laboratory, the shaking causes the animals to go down; after a period of quiet they come up again and form a dark-green scum on the surface of the sand. In this state they remain until, at the time when the rising tide is about to flood the part of the beach where the Convolutas live, they suddenly disappear. Some hours later, when the tide is running off the same part of the beach, a faint green colour appears on the sand, and in a minute or two the animals are all up again.

From this remarkable behaviour one might almost say that the animals are somehow or other aware of the rise and fall of the tide, or have a sort of "unconscious memory" that makes them keep time with the tide, although they are no longer on the beach. Further experiments, however, suggest another explanation. If the animals are kept in constant darkness they do not go up and down; they stay on the surface until they die. In fact, they do not show the rhythmic tidal movement unless they have been under a fairly strong light when they were in the "up" position. Thus exposure to light for about five or six hours seems to effect changes which make Convoluta respond to gravity by sinking into the sand. In the darkness it gradually regains its original normal state and reverses its response to gravity.

Similar changes in response are not unknown in both plants and animals; they suggest that it is not necessary to appeal to a mysterious "memory" to explain the curious behaviour.

It is important to remember that the animal that lives so elaborate a life is itself very simple, with none of the complicated nerves and other organs of the higher animals. It belongs to the world of chemistry and physics. And here we may quote Sir Frederick Keeble again: "It has yet to be proved that the higher animals differ in any fundamental respect from more lowly forms of life. Hence if, as a physiologist must hold, such differences as exist between higher and lower forms are differences of degree and not of kind, it follows that an increased knowledge of the nature of the lower organisms connotes also an increase in knowledge with respect to the higher organisms."

This argument is borne out by the fact that when we study the elementary nerve system found in worms we discover a pattern which is a kind of rough outline of the nerve systems in higher animals. In the simplest worms, such as the flatworm, the nerve system is not much more elaborate than that of the jellyfish, but the arrangement is different. In the higher worms, such as the earthworm, the nerve system is more than a net of nerves. Each segment of an earthworm has two nerve junctions, called ganglia, which are connected together across the segment. Each pair of ganglions, or ganglia, is connected with the ganglia in the next-door segments. So we can

picture this combination of ganglia with crosswise and lengthwise connections as a ladder running the length of the worm.

From the outer part of each segment sensory nerves—nerves of feeling—run to the ganglia in the segment. And from the ganglia to the rings of muscles that form, as it were, the tyre of each segment, run motor nerves—nerves of action. The business of the ganglia is to

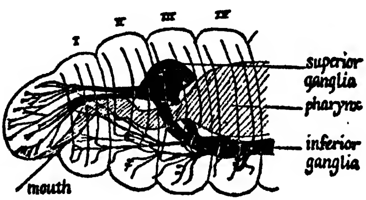


Fig. 11.—Earthworm: a brain section, much enlarged, showing the network of ganglia.

Fig. 12.—A simple crustacean, in which the nerve system resembles a ladder.

receive impulses from the sensory nerves and to send out impulses through the motor nerves. As the ganglia are connected to each other, they act as one in controlling the muscles on both the left and right sides of the body.

It is worth while dwelling a little on this nerve mechanism because it provides a kind of master pattern. When a doctor wants to find out the condition of our nerves, he asks us to sit with our legs crossed at the knees, and he taps the upper knee just below the knee-

cap; the vigour of the resulting involuntary kick indicates the tone of our nerves. This is a "reflex action," typical of many others that take place in our bodies, though in most cases we are unaware of them. A sensory nerve, a centre of adjustment, and a motor nerve—such is the basic pattern of a nerve system from the lower animals right up to man. Sir Charles Sherrington has expressed this truth in a vivid sentence: "A knee-jerk 'kick' and a mathematical problem employ similar-looking cells."

Perhaps the most curious feature of the reflex pattern is that the ingoing and the outgoing nerves do not make direct contact with each other in the ganglion. The reflex arc, as the combination is called, is not a continuous line. As the sensory nerve reaches the ganglion it spreads out like the branches of a tree, and its branches are tangled around similar branches formed by the beginning, as it were, of the motor nerve. "Synapse" is the name given to this near-junction.

For convenience in description we have greatly simplified the nervous make-up of the worm. There is much more to it than a reflex apparatus in each segment and main connections between the segments. Many sensory nerves lead into the ganglion, and many motor nerves lead out of it, so that the ganglia can make a great variety of responses to messages from different parts of the body. Sensory nerves and motor nerves in different segments are also connected, enabling the worm to apply its reflexes to wriggling freely, to taking in food, digesting

it, and expelling waste in worm-casts, and in other necessary acts.

A worm, however, is more than a series of segments abundantly supplied with nerves. It has a head, furnished with a brain. The lengthwise nerves which we have described as forming the sides of a ladder end in a ganglion behind and on a higher level than the mouth. Linked with this ganglion is a smaller one, farther back and lower down. These two ganglia form the brain—a kind of central nerve station controlling the nerve substations in the segments. While the other ganglia look after local movements, the brain directs the behaviour of the worm as a whole.

In the worm, therefore, we reach a higher stage of organization than those of *C. roscoffensis* or the jellyfish. The actions of the worm are integrated by the brain, and it is easy to see that the brain could not control a long chain of segments, to say nothing of the organs of breathing, digestion, and reproduction, without the rapid communication provided by the nerve system. The word "rapid" may seem out of place for an animal that moves so slowly as a crawling worm, but its modest rate of progress is due to its peculiar mode of locomotion, not to the low-conducting power of its nerves. A worm moves by stretching segments and then pulling them together, the stiff, backward-sloping bristles on its body preventing any movement to the rear. The impulse to move is not sent to all the segments direct; what happens is that the movement of the first segment starts up the

second segment, and so on, segment by segment, down the line. Thus the leisurely travel of the worm is due to its physical build; its nerves, as nerves, are quite efficient.

Many experiments have been made on the ability of earthworms to learn new tricks and to remember them when learned. Some of them were carried out in a T-shaped tube; the worm was admitted at the end of the longest part, and when it reached the junction it had the choice of a free opening on the left or of taking the right-hand tube where it would meet a piece of sandpaper and a device for giving an electric shock. In one set of experiments the worms learned, after two hundred trials, to take the correct turning. When the electrical device was moved to the opposite side, the same worms learned, after sixty-five trials, to change their course and escape.

In the light of such remarkable results, it is tempting to give the worm's brain, small as it is, good marks for intelligence. Further experiments, however, showed how little the brain had to do with the worms' performance. When the brain of trained worms—that is to say, worms that had learned to take the correct turn over and over again without hesitating—was removed, the brainless worms did exactly the same as the complete worms. And when untrained worms had their brains, and even some of the adjoining segments, removed, the remainders were able to learn to take the correct turn.

No one, of course, will credit a chain of worm segments with even a glimmer of intelligence. Its actions are as unconscious as those of the amœba, although the nerve-

muscle mechanism of the worm segment is so much more elaborate and efficient than that of the amœba. At the worm level we are far below the stage of evolution where we can say that an animal is conscious. Nevertheless, it is well to remember that while we talk about nerve-muscle mechanism, the animal machine is not the same as an ordinary machine, which is made to do one thing, or a series of things, and nothing else. As the worm experiments, and even the behaviour of the amœba, show, the animal machine is able to adapt itself to changed conditions. The power of adapting itself may be very slight; all the same, it is there, and it has played a very important part in evolution. The "survival of the fittest" has often meant the survival of the species best able to fit themselves to changes of climate, food supply, and so on.

CHAPTER IV

THE BEGINNINGS OF BRAIN

THE nerve pattern in the worm is repeated, with variations, in spiders, insects, and lobsters, crabs, and other crustaceans. These groups of jointed, backboneless animals are, in fact, believed to be descendants of worm-like ancestors. For our particular purpose, there is no need to describe the differences between the nerve systems of various groups or members of a group. The whole collection forms a branch from the main trunk of animal evolution, and the remainder of our story lies with backboned animals—fishes, reptiles, mammals, and men. They occupy the upper rungs of the ladder of life.

On the other hand, insects—notably bees and ants—offer so many fascinating examples of animal behaviour and have been so closely studied that they cannot be passed over.

One broad difference between the higher worms and the insects is that in the insect the brain is more highly developed and more important as a centre of control. The earthworm, as we have seen, can get along fairly well without its brain, but if the brain of a moth is removed, the animal cannot mate or lay eggs, neither can it choose the proper kind of leaf for egg-laying. Such

operations are typical examples of animal instincts—inborn tendencies to perform certain actions, which are sometimes very elaborate, and are always carried out with great precision.

The more highly developed brain of the insect therefore dominates the rest of the animal, and imposes an almost despotic rule over the movements of the various organs. Observer after observer has noted, with admiration, the way insects follow an inflexible routine. It seems, indeed, as if government by the brain was concerned only with obedience to instinct and had killed all power of adaptation to changing conditions. As if, in short, the insect were a rigid machine, not a plastic one.

But this is not quite so, even in the case of hive insects, each of which has a special duty to fulfil and a special brain and body-structure to enable it to carry it out. Experiments with ants prove that all these insects do not behave in exactly the same way under novel conditions. For example, when a number of ants were carried from the nest to a low platform connected with the nest by an inclined plane, some of them found their way back much more readily than others. One marked ant learned the way quickly and made trip after trip, carrying pupæ back to the nest, while another marked ant wandered about the platform, looking over the edge and refusing to use the incline even when pushed to the top of it.

One of the most quoted of Darwin's sayings is his reference, in *The Descent of Man*, to the brain of the ant. "It is certain," he wrote, "that there may be extra-

ordinary activity with an extremely small absolute mass of nervous matter; thus the wonderfully diversified instincts, mental powers, and affections of ants are notorious, yet their cerebral ganglia are not so large as the quarter of a small pin's head. Under this point of view, the brain of an ant is one of the most marvellous atoms of matter in the world, perhaps more so than the brain of Man."

Darwin's enthusiasm will be shared by everyone who has watched ants at work, but was he quite justified in putting the ant's brain on a higher level of wonder than the human brain? After all, the *individual ant* lives a simple and monotonous life; rarely is the insect called upon—as a human being so often is—to adapt itself to changed conditions. What is most marvellous about the ant is the complex community life, and that depends on each member of the various classes of ant—soldiers, workers, and so on—doing its routine job over and over again in the same old way. Ants, therefore, are little robots. In admitting this, however, we must remember that no animals are *perfect* robots. As we have seen, even the simplest organisms, such as the amœba, with no nervous systems at all, are in some degree plastic.

The question we now have to ask ourselves is why all the backboneless animals—the invertebrates—are in dead ends of evolution.

The answer is that they were not built so that they could develop larger brains. In the worm, which we described briefly in Chapter III, the two ganglia forming

the brain are respectively above and below the gullet, which is ringed by nerve tissue connecting the ganglia. So, if the brain grows, it will tend to squeeze the gullet and interfere with the intake of food. This arrangement is typical of the invertebrates, and it puts them on the horns of a dilemma. If they try to go up the ladder of life, they put their food supply in danger; if they continue to feed freely, they cannot acquire a better brain.

The dilemma is real. In some scorpions and spider-like animals the brain has grown so much and squeezed the gullet into such a narrow tube that only fluids can pass into the stomach. These animals have become bloodsuckers. In spite of their bigger brain—or rather, because of it—they have dropped down the ladder. Were they able to speak in their own defence, they would say that they could not help themselves.

A different design, therefore, was needed if animals were to develop bigger and better brains without committing suicide or becoming mere bloodsuckers.

In worms and other invertebrates the ladder-like nerve system lies on the lower or ventral side of the animal. In vertebrates it lies on the other side—the dorsal side. Further, the main nerves, instead of forming a chain through the lower tissues, are tucked into a tube running along the back. By examining the human embryo at various stages of growth within the womb, we can see how this tube developed. First a groove appears in the skin down the middle line of the back; then it deepens and the edges curl inwards until a tube is formed.

The skin cells thus enclosed develop into the trunk-line system of nerves we call the spinal cord, which is duly protected by the backbone. This same process can be followed in the living egg of the frog with the aid of a hand lens.

"The skin of the back," wrote Professors Wood-Jones and Porteous in *The Matrix of the Mind*, "seems such a strange thing of which to make a nervous system; but

FIG. 13.—A typical fly, shown in half-section, showing the connexion of the thoracic and abdominal ganglia.

it must be remembered that the skin of the back is made of cells which are specially sensitized to the environment, and cells, possessing this property, can be spared to elaborate and go through their evolutions in a region in which no other disturbance is taking place. It is a quiet region, and one not otherwise occupied; maybe that is why the great task of forming the nervous system is given over to it."

When it reaches the head, the nerve tube enlarges to form the brain. Being placed above the gullet, the ver-

tebrate brain can grow without interfering with the passage of food. The problem for the vertebrate was not to reconcile an open gullet with a large brain but to accommodate the organs of sight, hearing, and taste along with the brain at the business end of the animal. Here the eyes, which had to be well to the fore, presented the main difficulty, though not an insuperable one.

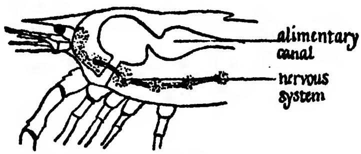


FIG. 14.—An invertebrate, in which the nervous system lies on the lower or ventral side.

In this arrangement of a spinal cord expanding at the head into a brain we have a compact nerve system for linking together in an orderly way (or correlating) the various activities of the animal. The structure of the system is complex beyond words; in one cubic centimetre of brain-matter there may be 20,000,000 nerve units. Nevertheless, it is possible to give a fairly simple picture of the way the system works. The complexity is largely due to the multiplication of nerve units of similar pattern.

As we saw in an earlier chapter, the nerve unit of the worm consists of a sensory nerve in alliance with a motor nerve. The spinal cord of the vertebrates contains both sensory and motor nerves, the sensory nerves lying on the dorsal side (where the sides of the groove

closed to form a tube) and the motor nerves on the ventral side. From the trunk system of sensory nerves branches run to the sense organs, the skin, and various

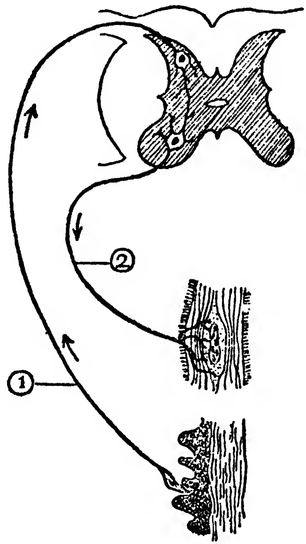


FIG. 15.—The Reflex Arc. To the spinal cord is shown proceeding (1) an incoming nerve fibre from a sense organ in the skin to a cell within the cord. Here it breaks into many small branches which make a synapse or contact with another nerve cell from which proceeds (2) an outgoing motor nerve fibre which conveys the stimulus to the muscle, gland, or other work-performing organ. This, being excited into action by the conveyed stimulus, makes the appropriate response.

parts of the body, so that messages from eyes, nose, and so on are carried to the spinal cord, and thence up to nerve centres in the central brain. The response to any such message is sent by the nerve centre through the motor

nerves in the spinal cord, and through branches therefrom to the limbs and other parts.

Once more, therefore, we find the simple "reflex action" noted in the worm and other invertebrates. Many reflex actions take place "on their own," as it were. We ourselves are not aware of the reflexes that effect the digestion and passage of food in our bodies, or those that keep us balanced as we move about. Other reflexes, such as those concerned in the beating of the heart or in breathing, produce effects of which we are conscious, but they go on continuously night and day, sleeping or waking, all through our lives, and our power of modifying them is either nil or extremely limited. It is salutary to remember how much of our existence lies in this underworld of reflexes, as it bears upon the question of how far we, who have the most highly developed brain in the animal world, are masters of ourselves.

Among the lower vertebrates, such as fishes, the entire brain is concerned mainly with reflex activities, and there is little in their behaviour that shows anything that can be properly called intelligence. The main difference between them and the invertebrates we have described is that their reflexes are more complex and more efficiently linked together. Not only is each part of the brain of a fish connected with a particular sense organ, such as the eye, the nose, or the "taste-buds" on the skin, but the various parts of the brain are linked together by nerve fibres. Thus the nervous system of the fish is at once

more elaborate and better integrated than that of the insects, and the range of its reflexes is much wider, providing regular and automatic adjustments to a greater variety of conditions.

At the same time, the fish is not limited to purely reflex and instinctive behaviour. Once again we have to recognize the plastic quality of an organism that appears to be a bundle of rigid reflexes. Fishes can be taught to thread a maze and to change even their feeding habits. A perch and a pike were placed in a tank separated by a glass partition from another tank containing minnows, which are their natural food. After dashing themselves against the partition over and over again, the fishes gave it up—and gave it up so thoroughly that when the partition was removed they refrained from trying to catch the minnows then swimming around them. To this extent their reflexes had been "conditioned" by a special experience.

At this stage in evolution we can say that the brain has become the agent which correlates movements in response to sense impressions. But we can hardly say that it controls the movements. To quote *The Matrix of the Mind* again: "The animal is equipped for dealing with the immediate demands of its normal routine of life, but it is obvious that the routine must needs be a somewhat restricted one. Its life may be said to consist in the performance of appropriate actions begot in response to biologically-relevant stimuli. The animal does not manifest its activities in the performance of ever-varying

responses in ever-varying conditions. It does not lead a life of lights and shades of response; it does not exercise that deliberated choice of action such as is manifested by animals more advanced in the evolutionary scale."

How was this upward step to a brain capable of "deliberated choice" taken? Not by a simple growth of the brain as a whole. Among the lower vertebrates, such as the fishes, the various ganglia that form the brain are rather solid masses of cells, yet in the course of evolution they developed thin, hollow outgrowths, one on each side of the fore part. In the brain of the fish these outgrowths have only begun to appear: in the reptile and the bird, which are higher up the vertebrate scale, they are more developed; in the mammals—the group to which Man belongs—they form the largest part of the brain.

Here they are called the "cerebral hemispheres" and in their fullest development—which we find, of course, in Man—they stand on the highest rung of the ladder of life.

CHAPTER V

FOLLOWING THEIR NOSES

A GREAT deal has been written on the question of how far animals lower in the scale than Man display intelligence and reasoning power. And the answers given to the question vary within wide limits. Some people, for example, do not hesitate to talk about the wonderful intelligence of the ant or the bee; others point out that these insects have only primitive brains and behave like robots. Again, one often hears people describing their dogs as "almost human," while others maintain that a dog's life is an affair of reflexes, which may, however, be conditioned by training, and that a clever dog differs from a dull one solely in being more easily conditioned.

All such debates are largely a quarrel over words. If we consider that the behaviour of animals depends on their structure, and especially on the pattern of their nervous system, and that the development of structure and pattern has been continuous from a form of life which was just over the threshold of not-life, we realize how difficult it is to put our finger on various points and say "Here was the dawn of conscious life" or "This was the first animal able to reason." In making the attempt

at pin-point beginnings of this sort we are applying what we learn from looking into ourselves or watching other humans to organisms simpler in structure and different in nerve pattern from ourselves, though we are closely related to them. We are thus in danger of reading something human into animal behaviour that is a long way from being human.

So, while we ourselves know what we mean when we say that *we* are conscious beings—indeed, that we are self-conscious in the sense of being aware of ourselves as individuals among other individuals—and know that we can reason, it is not easy for us to define consciousness, self-consciousness, and reason in a way that will provide us with a yardstick for measuring the mental faculties of other animals. We can, however, make progress in understanding the workings of our own minds by examining the nerve structure and pattern and behaviour of our brains. That is the field in which the anatomist and the physiologist operate, and their findings are supplemented by the psychologist, who studies our behaviour as individuals.

The same two methods can, of course, be used to throw light on the animal mind, which is related to the human mind as the simple is to the complex, or, rather, as the complex is to the more complex. At their first appearance the cerebral hemispheres were comparatively (but only comparatively) simple affairs, consisting of masses of pulpy white brain-matter with a smooth rind of "grey matter" made up of innumerable nerve cells.

The sensory nerves from the spinal cord were connected, through the lower brain centres, with the cells in the rind—or "cerebral cortex," as it is called. Cells in the cortex were also connected by a special tract of nerve fibres down the spinal cord to the motor nerves.

Thus was added a new mechanism to what we may call the old standard pattern of spinal cord and ganglions directly linking the sensory and motor nerves in a network of reflex actions. Although the cerebral hemispheres grow out of the solid brain and are intimately connected with it, they seem to stand apart from it, or at least above it in purpose as well as position. The microscopic sensory nerves entering the hemispheres do not go singly and at random; they are grouped together in fibres after the pattern of telephone cables, and the fibres served by the different senses proceed to separate sections of the cortex. There are, moreover, cross-connections—"association fibres"—among the fibres serving the various senses and also among those concerned with movement. Again, there is a main cross-connection between the two hemispheres.

From this pattern we can almost guess the purpose of the hemispheres. They form a kind of super-brain equipped for the business of deciding and controlling the movements of the animal. The impulses sent along from the senses are gathered together by the association fibres in the brain and received by the cortex, which responds to their joint message by sending the appro-

priate impulses down the motor nerves. As the right hemisphere is connected with the nerves governing the left side of the animal, and the left hemisphere with the right side, the cross-connection between the two ensures that the two sides are moved in harmony. The cerebral hemispheres thus form a true " central station " for the whole nerve and muscle system; they provide an " organ that is developed in order to permit the animal as an individual, and not merely as the child of a definite line of ancestry, to deal with the varied stimuli that may affect it as an individual."

While the pattern we have described forms the ground-plan of the nerve and brain system of the backboned animals, it varies greatly as we rise from the lower animals to the higher. In each animal the size and the degree of elaboration of the various parts are related to the way of life of that particular animal. And as its needs are signalled by the sensory organs—sight, smell, hearing, taste, and touch—the make-up of the brain corresponds with the arrangement of the sense organs and with their order of importance.

It is not always realized how this order of importance differs among animals. Human beings have a sense of smell; with some of them it is acute, with others it is dull, and with a few it is, for one reason or another, of little or no account. But whether we have a sensitive nose or one that is practically useless is not a vital matter to us. Among the lower vertebrates it would, on the other hand, be a matter of life and death. The fact

that the nose is the leading organ in the head that leads the vertebrate is not a meaningless detail of design. Many animals "follow their noses" in more ways than one. We need think only of hounds on the trail to appreciate how important a part a sensitive nose may play.

So it was in the natural order of things that the cerebral hemispheres should make their first appearance on behalf of the nose. Among the lowest vertebrates, such as some fishes, the cerebral hemispheres are "olfactory bulbs." As we use our sense of smell by sniffing the air, it seems peculiar to talk of a fish smelling under water. Smell, however, is a chemical sense; it operates when vapours or dust particles carried by the air meet the moist inner surface of the nostril and set up chemical reactions. It is closely associated with the sense of taste —also a chemical reaction. The flavour of food we eat is a combination of taste and smell.

No one can say, of course, that a fish, when it smells anything, has a sensation similar to our own when we sniff the air. On the other hand, we can say, from study of the evolution of the brain, that the olfactory bulbs that dominate the nerve mechanism of the fish were the forerunner of the sections of higher animal brains concerned with sensations of smell. Their job was to aid the fish in the search for food, and they did it so well that the fish could afford to leave the rest of its sensory system at the old level of reflex action. So long as the fish remained in the unchanging environment

of the sea there was no call for a radical change in its make-up.

The further development of the cerebral hemispheres came with the change from life in the sea to life on land. We need not go into detail about the alterations in land levels that caused the change, or about the novel ways of breathing, of moving, and of feeding that the change made necessary. What interests us is the effect of the transformation upon the development of the brain.

Broadly, the effect was that the cerebral hemispheres which had been reserved for olfactory nerves were invaded by nerves concerned with other senses. The hemispheres grew to make room for the newcomers, and became more elaborate in structure to afford flexible control of all the bodily activities. Messages from all the centres thus reached the cerebral cortex (that all-important layer of cells), each type of sensory impression being registered in a different region of the cortex, and all of them being correlated by the association fibres already described.

With a complex brain-equipment of this kind, an animal is well equipped to meet the numerous and varying demands of life on land.

In the lungfish, which is able to breathe in water and also in air, we have a surviving example of the transition stage between the fish and the amphibian. The brain of the lungfish has well-developed hemispheres of thin-walled pattern which is suited to expansion into more complex hemispheres like those found in the higher

vertebrates. All the amphibians—frogs, toads, salamanders, and so on—show the same general pattern as the lungfish. Indeed, from the lungfish and through the lower amphibians to the higher, there is a gradual change in the form of the cerebral hemispheres, leading right up to the higher vertebrate (including the human) form. The ground-plan remains constant; the size and the complexity of the walls of the hemisphere are the main features that change.

It is worth noting in passing that the advance from sea to land life, which we have described in a few sentences, occupied an immense period of time.

Even after the " other senses " had found their footing in the cerebral hemispheres, the olfactory bulbs held their superior position for a long time. Indeed, if land animals had kept strictly to the land, the nose might have remained their chief sense organ. But they did not all confine themselves to crawling or burrowing, or walking on all fours, nose on ground. They took to flying or to living in trees; they also learned to swim.

Before dealing with the brain changes that resulted from this rise in the world, it is worth while pausing for a moment to consider what an important part " nosey " animals played and still play in Nature's zoo. The world of the lower vertebrates was, and still is, a world of smell. Sight, hearing, and touch helped, of course, in the search for food and the detection of enemies, but they were only assistants to the main guide. When the first small mammals appeared on the scene with hairy

coats to preserve body-heat, the nostrils remained bare and—an important point—they were continually kept moist to make the sense of smell as sensitive as possible. Fishes have no eyelids, and the land animals that descended from them likewise had no protecting lids. Their eyes "watered," and the flow of moisture, after cleansing the exposed surface of the eye, trickled down to the open nostril. A similar mechanism survives in our heads, although our sense of smell is comparatively feeble; when we cry we always wind up with blowing the nose to clear away the moisture that has passed from the eyes into the nostrils.

In saying that "the wet-nosed animals are the aristocrats of the smell world," Professors Wood-Jones and Porteous are only stating a scientific truth in a picturesque way. These animals are able to determine the nature, position, direction, and possibly the distance of anything by means of a single sensory organ. We can only dimly imagine the complexity of the smell sensations that a dog receives and interprets—distinguishing one from another—with his wet nose. Experiments made in the last century by Professor Romanes showed that a setter could follow his master's trail, although eleven men had crossed it after it had been made.

It is probable that a dog's instant dislike for certain people, and for certain classes of people, is connected with its acute and sensitive sense of smell. And although our sense of smell has been described as a "ridiculous apology" it may have something to do with the "in-

stinctive" aversion inspired in us by some people on our first meeting. Further, it may account for the feeling, occasionally experienced after one has been sitting alone and closely occupied for a time, that there is someone else in the room. In these cases a signal from the olfactory nerves may affect our mind, although we are not directly aware of a smell.

Such speculations, however, are a diversion from our main purpose, which is to trace what happened to the pattern of the brain when animals mainly dependent on their sense of smell adventured into regions where smell was of little or no use to them.

Consider, for example, the reptiles, and their descendants the birds. In the alligator, which is at the top of the reptile scale, the olfactory bulbs form a prominent part of the brain in relation to the cerebral hemispheres; in the bird, the bulbs are much smaller in comparison with the hemispheres. This change definitely puts birds on a higher evolutionary level than reptiles, but it was accompanied by a serious backward step. Although the bird's hemispheres are larger, the cortex—which, as we have indicated, is the seat of the highest mental activity—is reduced in amount, and is more primitive in its structure.

From a brain-pattern of this kind an expert could deduce the habits of the animal concerned. The increase in the size of the hemispheres indicates an enlargement of instinctive life; the reduction of the cortex in size and elaboration suggests a falling-off in powers of learning

and of making adjustments to new conditions. Now everybody knows that birds, with their nest-making, their migrations and homing habits, live a very complex life of instinct; at the same time, their intelligence is not on the level of that of the dog or cat, whose instinctive life is much simpler.

In this case, as in others where instinctive behaviour and adaptability are concerned, the domination of inherited habits is not complete. Birds can modify their habits in many ways; much of the interest aroused in ornithologists, professional and amateur, is due to the variety of such modifications. Similarly, the popular custom of keeping canaries is a tribute to the intelligence and adaptability of birds. Nevertheless, it remains true that inherited habits are the main factor in their behaviour. The pattern of their brains provides the reason for the fact that birds, like insects, are an offshoot from the main stem of animal evolution.

Returning to the main stem, we find that it was ascended by animals that adapted themselves to life, not in the upper air, but in trees. As with the birds, the new environment made the sense of smell of much less use than before; it also brought fresh demands on muscles, eyes, and ears in climbing, the search for food, and the detection and eluding of enemies. All the animals which made the change were by no means equally clever in adapting their ways to arboreal life, but whatever the alteration in their habits, it was faithfully reflected in their brain structure. The smell part of the cerebral

hemispheres gradually dwindled, and the parts controlling the other sense organs became larger and better organized.

Among primitive mammals, which lived on the ground level, the smell mechanism occupies about half of the brain. In the opossum—a tree-living animal—the proportion has sunk to one-third, showing that the animal had gone some way in overcoming the old supremacy of the sense of smell. In the lemur—a tree-living animal that has the honour of being the modern representative of a direct ancestor of the higher mammals and therefore of Man—the smell-brain is only a small fraction of the whole.

To go higher still: in the brain of the monkey the smell-brain is so small that the anatomist has some difficulty in locating it. In the human brain it occupies less than a hundredth part of the cerebral hemispheres and has degenerated into a tangle of sensory nerves, ganglions, cortical cells, and connecting fibres, among which the ancestral parts of the once-dominant smell-brain can hardly be distinguished.

The advantages gained from a fading out of the smell-brain and its substitution by a brain concerned chiefly with sense impressions from sight, sound, and touch cannot be summed up by saying that animals had three well-developed senses to help them in place of one. Wonderful as is the sense of smell, it has its limitations, even at the stage of perfection it reached among the wet-nosed animals. It is, as we have noted, a chemical sense, and is aroused only when something

carried on the wind touches the nostril or when the animal, sniffing from place to place, encounters a scent that invites him to a meal or warns him of the nearness of an enemy.

On the other hand, sight and sound bring messages from a distance—messages that are much more informative than a mere smell. Sight embraces form, direction, distance, and the line and speed of movement. Sound supplements sight by locating prey or enemies that are out of sight; it also helps to determine distance, direction, and movement, and in the case of roving beasts of prey, the temper and purpose of the enemy. Touch, again, gives a direct experience of form, weight, and texture, and it serves to guide bodily movements.

By developing the use of these three senses, an animal greatly extends and enriches its experience of the outside world. And as its experience grows and becomes more varied, the brain is called upon to handle an ever-increasing multitude of messages, to correlate them, and to arrange the appropriate responses. All this complicated brainwork demands a bigger and better cortex as a clearing-house for the impulses coming through the various senses, and as an organ capable of weighing up the impulses and making a decision which will lead the animal to its prey, or effect its escape from danger, or otherwise enable it to survive.

The eminent physiologist Sir Charles Sherrington has, in his book on *The Integrative Action of the Nervous System*, given a very vivid picture of the elaborate series of

activities set up in an animal by the long-distance senses. He takes the case of a flesh-eating beast pursuing and seizing its prey. In the preliminary stages (which are all directed to serve the end in view) the animal has to be constantly adjusting its actions to messages received through eye and ear. During the whole proceedings, which may take quite a long time, the animal is in an intensely nervous state and engaged in continuous muscular activity. The longer the hunt lasts, the more intricate become the processes going on in its brain. Every sense is alert to note each new move of the quarry and to take advantage of the lie of the land. Or the quarry may be stalked with a cautious approach in which every possible accident is foreseen and guarded against.

Here we have a much more complex and exacting process than is involved in a smell-governed animal following a scent. The nearer an animal stands to Man the more it depends for its survival on its long-distance senses and on the ability of its cerebral cortex to deal in an orderly way with the endless and ever-changing stream of nerve messages. Man stands above the other animals not because his senses are superior—they are little better, if anything, than those of the apes—but because he can, through his larger, more elaborate, and more highly organized brain, do much more with them.

In a later chapter we shall try to give an outline of the pattern and working of the human brain, in spite of what Sir Charles Sherrington aptly calls its "unspeakable complexity." At this point, however, we may note that

the unspeakable complexity is linked with an amazing simplicity, which runs right through the kingdom of life.

"On the old evolutionary view," Dr. C. F. A. Pantin has said, "organisms were like putty to be moulded in any way whatever by the natural selection of small random variations. The materials of which organisms are, in fact, built are not so much comparable to putty as to the standard parts of a child's constructional set, each with the limitations imposed by its own structure. The number of kinds of more complex forms that can emerge is limited." [1]

When we think of the great variety of forms of life that inhabit or once inhabited the earth, we may feel inclined to dispute the view that there is a limit to the designs that Nature can evolve. But when we look closely into the structure of living things, we see that all the various forms arise from different arrangements of similar basic-cell units. And we also see, from the fate of the giant dinosaurs and other "freaks of Nature," that there is a limit to the arrangements that will "work" by enabling the animal to survive. Another reminder that animal patterns are not moulded like putty comes from the ability of biologists to "reconstruct" an entire animal from a few fragments of its fossilized skeleton.

For the purpose of this book, however, there is no need to enlarge on the argument as regards animal forms in general. We are concerned only with nerve patterns,

[1] *Nature*, April 15, 1950.

and here we have a clear example of unit construction. All nerve systems, from the jellyfish up to Man, are made up of nerve-cell units. In the jellyfish the nerve system is simple; in Man it is baffling in its complexity, owing to the multiplication of the units by millions and to the intricacy of their interconnections.

From this point of view, Man may be described as Nature's masterpiece of unit construction.

CHAPTER VI

THE LEARNING BRAIN

At the beginning of the previous chapter a brief reference was made to the study of behaviour by the psychologist. Instead of relating behaviour to the nerve structure that governs it, the psychologist may study the behaviour of animals as individuals, comparing the behaviour of one species with that of another, and making experiments to discover how various animals react to unusual conditions. In the case of Man himself, he observes behaviour not only from the outside, but by "introspection," the examination of what goes on in his own mind.

Numberless books have been written about the behaviour of animals in the wild and in the domesticated state, and under test conditions. But out of this storehouse, which contains much that is more romantic than scientific, we shall pick only a few scraps which help to fill in our picture of the evolution of mind. In making our selection we shall concern ourselves particularly with the process of learning. As we often measure the mental capacity of human beings by their ability to learn, and as quite lowly animals are able to learn new habits and remember them, such light as the psychologist may throw

upon the business of learning is an aid in understanding the working of our minds.

Among the lower animals little or no time is spent in learning. For example, insects appear as a finished article, fully equipped for life; even alligators, when hatched out of the egg, swim around and snap as viciously as the fully-grown animal. In birds, which are more highly organized, there is a period of learning as well as growth after they emerge from the egg. The late Professor C. Lloyd Morgan carried out a number of interesting experiments with chicks hatched in an incubator and kept secluded for about a day—these precautions being taken to ensure that the behaviour of the chicks would be unaffected by maternal influence. When released, they would cheep, walk, and also peck, with fair but not complete accuracy, at crumbs or bits of white of egg. A fly with clipped wings would be followed and pecked at, but not caught or swallowed till the sixth or seventh peck. When a shallow tin containing water was placed among them, they would often take no notice; but if a chick pecked at a bubble or something in the water, or happened to wet its feet, it would immediately lift its head in the peculiar way of birds when they drink.

One chick pecked at its own excrement three times in quick succession, then shook its head and wiped its bill on the ground. Ten minutes later it began again to peck at its excrement, but checked the action before its beak touched; and again it wiped its bill. A little later it

again came near the excrement, but this time it just looked and walked away.

From these experiments it may be gathered that although chicks seem to us little automatons, they begin very early to control their movements. They have a nerve mechanism which induces them to peck at small objects; this is a definite reflex action. Nevertheless, their pecking is only fairly accurate; generally, at the first trials, they strike a little short, and later—after practice and under the stimulus of the scramble for food—they become perfect. Similarly they learn to discriminate between pleasant and unpleasant objects.

In this process of learning the cerebral cortex plays the dominant part. It controls the pecking action, for example, making it more and more correct. It also seems to associate the appearance of certain objects with desirable or undesirable qualities. Within its limited range, therefore, the chick learns by experience.

Some psychologists have been inclined to credit animals of various sorts with a kind of "ancestral memory" which enables them to do the right thing in new situations. If such a memory were possessed by a chick, we should expect every chick to respond to the clucking and fussing of a hen. But when Professor Lloyd Morgan took some ten-day-old chicks, which had never seen a hen, to a poultry yard, they took absolutely no notice of the clucking hen. Likewise, they took no notice of a cat—one of the ancestral enemies of all birds.

So we can draw a clear distinction between a perfect

instinct and an instinctive habit which can be improved with the aid of cerebral control. A perfect instinct is one that never varies, serves the needs of the animal completely, and requires no intelligent guidance or training. As Professor Lloyd Morgan puts it: "If the chicks had pecked perfectly from the first they would have had this instinct in perfection. As it was, they required a little intelligence, acting by and through experience, to perfect their activities. The instincts were very nearly, but not quite, perfect."

As we go up the animal scale we find this capacity for control, for learning by experience and trial and error, growing greater in line with the size and complexity of the cerebral hemispheres. It also grows with the length of time that the young take to reach the adult stage, when they can look after themselves. And, again, it grows with the amount of trouble that parent animals take in teaching their young. We have all, for example, been impressed by the remarkable tricks performed by sea-lions; they are more wonderful even than those of dogs and horses, which are looked upon as more intelligent than sea-lions. A young sea-lion has all the reflexes needed to enable it to swim and to catch fish under water, but the mother sea-lion is accustomed to take her cub time and again into the sea and encourage it to imitate her and develop her delicate balance and swift purposeful movements.

While the training of a human child is akin to that of the higher animals, it takes a longer time and involves

greater demands in the way of mental processes. Man has been called " the tool-using animal," and the ability to make and use tools is certainly one faculty—though by no means the only one—that distinguishes us from the animals. In a crude way the apes, which are our nearest relations, can use tools, as when they reach for bananas with a stick or throw a stone. Man, however, has a better hand for tool-using, and a better brain to enable him to shape and apply tools.

The development of the human hand seems to have begun when our animal ancestors, after having taken to the trees, came down to earth again. Life in trees called for good sight, good hearing, and great agility, but it was not so exacting or so dangerous as life on the ground for an animal which had been a fruit- and insect-eater and had lost its keen sense of smell. The change would have been fatal if man-to-be had not contrived to adapt himself to it in various ways.

One way was to acquire an erect posture, instead of walking on all fours, and to develop, from a fore-paw used mainly for support and for swinging from branch to branch, a hand capable of building and manipulating objects with great skill. A most important detail in human evolution was the appearance of our " opposable thumb "—an apparently trifling change from the ancestral pattern of five digits curving in the same direction, but one which made a world of difference to our prospects of becoming a tool-using animal. The human hand is, in fact, a wonderfully strong, delicate, and adaptable instru-

ment not only for the shaping of objects with the aid of tools, but also for testing weight, hardness, smoothness, texture, warmth, and other qualities. In alliance with the eye it served to broaden Man's experience of the world around him and to help him to adapt himself to new surroundings. At the same time, the wealth of impressions coming from hand and eye in partnership stimulated his intelligence.

Another factor that helped ancestral man was the dawn of speech. So accustomed are we to speaking of "dumb animals" that we are inclined to assume that the power of speech is exclusively human. Bearing in mind, however, our evolution from the animals we might expect to find, in the "dumb creation," a foreshadowing of the human faculty. Although animals carry on their daily lives of responses to impressions from the senses of seeing, hearing, smelling, and touch without need of words, they have some power of expressing themselves and communicating with their fellows by voice and also by gesture, which with us is a familiar aid to speech. Our gestures are far more varied and full of shades of meaning than those even of the animals nearest to the human level. As Professor Geoffrey Jefferson reminds us, what makes the pantomime cat or horse so funny and delightful is to see it making gestures that are entirely human—the beckoning paw, the wink, the shrugged shoulders, the expressive posture: "We see in these artificialities the elaboration of something that we have in common, and we recognize what we had hardly suspected, that even simple gestures

require a richly integrated nervous system to permit their use." Similarly, we have carried communication by sound to a pitch far above anything possible to the animal brain. In our power to express ideas we stand alone; this power depends upon our power to put them into words.

There are several theories about the way in which the change (which must have taken a very long time) came about from animal sounds, which registered such emotions as fears and rage, to human utterances which identified objects by means of special sounds and conveyed specific orders for action. But there can be no difference of opinion about the advantage of such a means of communication to a species entering on a new world of life on land, where beasts of prey, immensely stronger, abounded. At this stage in evolution the human species was certainly gregarious, and, to quote *The Matrix of the Mind* again: "The development of vocal language evidently came about through the necessity of the leader of the group or herd to make imperative or guiding sounds, meaning being attached to them by appropriate gestures made when visual communication was possible."

When we consider how early man was handicapped in the struggle for existence among beasts so much larger and fiercer and more heavily armed than himself, the wonder is that he managed to survive. Many people surmise that his fate was often in the balance. The secret of his ultimate success lay in his larger and more complex and capable cerebral hemispheres; at this stage in evolution brain won over brute force.

With the aid of speech the most intelligent individuals were able to guide others in the search for food, in protecting themselves against enemies, and in acquiring primitive crafts. At a later stage, when the art of writing came into being, the experience gained in one generation could be recorded for the benefit of succeeding generations. The innate intelligence of modern man may not be greater than that of his primitive ancestors, but the modern child enters into an inheritance of knowledge infinitely greater than that enjoyed at the dawn of civilization.

Man, therefore, is the lord of creation by virtue of the achievements of his brain. While the human brain has evolved from the animal brain, it displays powers which mark it off very clearly from the best of animal brains. These special powers belong to the world of thought, and they appear to be closely related to the development of articulate speech. We can credit early man with the ability to distinguish, by sight or touch or both together, between smooth pebbles and rough stones, smooth bark and rough bark, smooth pools and rough rapids. He would, however, need some time and thought to realize that all the smooth things had a quality in common, though they were otherwise so different. But if a word were used to describe a pebble as distinct from a rough stone, it would be easier for him to reach the general idea of *smoothness*. We ourselves, by the aid of words, have no difficulty in grasping such an idea and extending it to poetry, or people's voices, or motion in a vehicle.

Again, early man was doubtless capable of observing that, when black clouds filled the sky, rain followed; that, when rain fell, rivers overflowed and vegetation appeared on parched soil. Sequences of this sort register even with animals. When a dog sees his master put on his hat and take a walking-stick, he expects to go for a walk; when a cat hears a spoon rattled against a saucer, he comes for his meal. The responses of the dog and cat are, however, merely reflexes. Pavlov and others have shown that such reflexes can be artificially "conditioned"; a dog accustomed to be given a meal after a bell has been rung, will water at the mouth at the sound. Man, confronted with sequences repeating themselves in the world around him, begins to be aware of regularities in Nature, of what we now call cause and effect. But he would hardly be able to begin reasoning about it in this way without words to describe the sequences and to express the ideas of "cause" and "effect."

The search for the *how* and the *why* is peculiar to Man, and Man conducts it in words. As Professor Lloyd Morgan wrote: "I surmise therefore—and one is not in a position to do more than surmise—that explanation, though it involves the higher faculty of conception, had its origin, not indeed coincidently with, but very shortly after the power of description."

Having glanced at behaviour as the comparative psychologist observes it, we turn to the recent discoveries of physiologists in the working of the human brain.

CHAPTER VII

NERVE IN ACTION

As the brain is of unit construction, the first step towards understanding how the brain works is to learn all we can about the nerve unit.

Each unit is like a comet with a long tail; the head is a microscopic nerve cell and the tail is a microscopic fibre. Its purpose is to carry messages—sensory messages—to the brain, or messages from one part of the brain to another, or motor messages to muscles and other parts of the body. What sort of messages are carried? And how are they carried?

These questions have been answered, at least in part, by a brilliant series of experiments carried out in this and other countries. They revealed that a "message" travelling along a nerve fibre is always accompanied by an electrical effect. When a nerve is roused to action, an electrical impulse moves along the fibre.

As might be expected, the impulse is extremely feeble. When the electrical pressure is measured at two points on a nerve carrying a message, the difference in pressure involved in the electrical wave is no more than a few hundredths of a volt. Moreover, it does not last for more than a few thousandths of a second. Early experimenters

were handicapped by the difficulty of measuring such minute and brief currents with the instruments at their disposal, but after the appearance of the radio valve that handicap was overcome. The electrical changes in a nerve can now be amplified to such a degree that they can be recorded by photography or by a pen on a moving chart.

In the human nerve the wave of activity travels at the rate of about one hundred feet per second. While we detect and measure the wave by its electrical effect, the wave is not just an electrical affair. It is marked by chemical changes in the nerve and also by the production of heat. So nerve action is generally described as an *electro-chemical* process.

In most of the experiments referred to, an electrical stimulus is used to excite the nerve. One might suspect, therefore, that the electrical nature of the stimulus has something to do with the electrical effect accompanying the wave of activity in the nerve. But this is not so. As Professor Adrian says: "Precisely similar electrical changes can be recorded in the nerves when they are working naturally, when the sense organs connected to them react to light, or sound or touch, and when the brain is sending its orders to the muscles. . . . In fact, records of the electrical activity of the nerves leave no doubt that there is only one kind of change which can be conducted down a nerve fibre, only one kind of impulse."

The claim that the electrical character of the impulse

has nothing to do with the electrical effect of the travelling wave is confirmed by the fact that the intensity of the nerve action cannot be changed by varying the strength of the stimulus. The intensity of the impulse depends on the energy in the nerve fibre itself. The stimulus is like the pressure of a finger on a trigger: in Professor Adrian's words, "either it is strong enough to fire the bullet or it is too weak to do anything. . . . There is an 'all or nothing' relation between the stimulus and the activity which it produces."

This does not mean, however, that it is impossible to raise or lower the total activity of a nerve fibre. If such a thing were impossible, we should not be able to tell the difference between a mild and a strong sensation. Nerve activity can be raised by increasing the speed with which impulses follow each other.

There is, it is interesting to note, a limit to this speed of follow-up, or frequency. When an impulse has passed any point on a nerve, a brief interval is needed for the nerve at that point to recover so as to be able to transmit another impulse. Nerve fibres, therefore, are not built for continuous transmission; they operate by a series of impulses, separated by definite intervals.

As, however, nerve fibres are arranged in bundles like multiple telephone cables, co-operation may make up for the limitations of the individual fibre. A strong stimulus, like a blow or the touch of a hot body, may excite more nerve fibres than does a weak one. Nevertheless, the main thing that makes the difference between a weak and

a strong sensation is the number of impulses per second in the nerve fibre.

This can be proved by a simple experiment. Professor Adrian took from a frog a small muscle and removed all but one of the end-organs attached by nerves to the muscle; thus he had only one nerve fibre in action. He then stimulated the nerve fibre by pulling the muscle —gently at first, then harder—and amplified the resulting

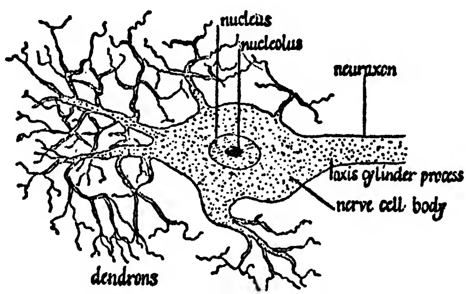


FIG. 16.—A typical nerve cell, greatly enlarged, showing the cell body with nucleus and nucleolus, a number of fine branches or dendrons contacting other cells, and an outgoing nerve fibre or axis cylinder process.

electrical waves for inspection. As the pull was increased, more and more waves were recorded. So, in the words of Professor A. V. Hill: "If anything feels hotter or heavier, or sounds louder or looks brighter, it is because it is *producing more messages every second* in the nerve fibres that carry the sensation to the brain."

In this quotation we are reminded of a very important feature of nerve action. Although our sensations of sight, sound, smell, taste, touch, and pain are so different

one from another, the nerve impulses that carry them are all very much alike. We cannot say that they are all *exactly* alike, since all nerve cells and fibres are not of precisely the same kind. But these variations in nerve units do not affect the claim that differences in sensation —light, sound, and so on—are not due to differences in the nature of the messages that give rise to sensation. Professor Adrian maintains that "everything goes to show that although there may be some variations there are no radical differences in the messages from different kinds of sense organ or different parts of the brain. Impulses travelling to the brain in the fibres of the auditory nerve make us hear sounds and impulses of the same kind arranged in much the same way in the optic nerve make us see sights. The mental result must differ because a different part of the brain receives the message and not because the message has a different form."

Before going on to describe something of the structure and working of the human brain, two sentences by Sir Charles Sherrington may be quoted as a reminder of the uniformity that underlies the complexity of the organ of mind: "The signalling which goes on in the nervous system is essentially electrical. . . . We do not dip a pen-nib into ink without generating an electric current."

CHAPTER VIII

THE BRAIN AT WORK

THERE are about ten thousand million nerve cells in the human brain. And if a slice of brain tissue is examined under the microscope it gives a picture of "seemingly reckless profusion of nerve cells"—thousands and thousands of nerve fibres running hither thither and intertwining and crossing in what looks like utter confusion.

Here, surely, is a maze in which Man must feel eternally lost. Yet he has contrived to trace some order in the apparent chaos. He has, as we have seen, learned that the confusion is due in part to the multiplicity of nerve units of the same basic pattern. He has also, as we shall presently see, been able to trace nerve connections through the tangle from one part of the brain to another. Further, he has thrown a good deal of light on the special functions of certain parts of the brain.

The easiest way to approach this difficult subject is to consider the general structure of the brain. Quite the most important feature is the pair of cerebral hemispheres —so massive in the human brain that they account for most of the total brain weight of about fifty ounces. From the point of view of mental activity the most

important part of the hemispheres is their thin cortex, or rind. The cortex is deeply corrugated, so that its total surface is very much greater than that of the skull which encloses and protects the hemispheres; indeed, more of the surface is tucked away in the folds than is visible when the skull is removed.

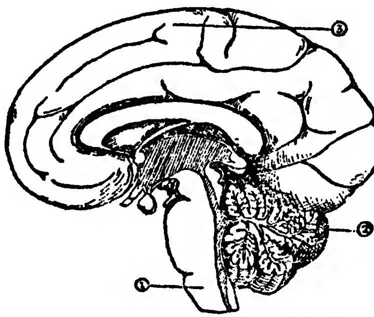


FIG. 17.—The human brain: a sectional side-view, showing (1) the medulla, (2) the cerebellum, and (3) a cerebral hemisphere. The front is to the left.

Under a microscope the cortical layer is a mass of closely packed nerve cells and fibres, forming what is called the "grey matter." Beneath it is pulpy "white matter" made up of nerve fibres running in all directions. This white matter fills up most of the interior of the hemispheres, and it encloses, near the base of the brain, various masses of grey matter which narrow down to the brain stem connecting the brain with the spinal cord.

Although the cortex appears to be a uniform sheet of layers of nerve cells and fibres, certain parts of it have special roles to perform. At the back of the brain is the

region concerned with sight; at the lower part near the middle is the area connected with smell, and above it is the hearing area. Looking at a brain from the side there is visible a wavy and almost verticle fissure that rejoices in the name of *sulcus centralis*; the strip of cortex immediately in front of the fissure sends messages to our muscles, and the strip immediately behind the fissure receives sensory messages from sense organs.

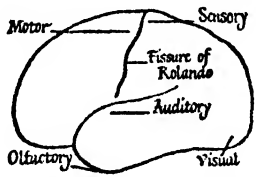


FIG. 18.—Diagram showing the five " projection areas " in the human brain.

As might be expected, the " projection areas," as these special regions are called, have direct connections through nerve fibres with sensory and motor organs. The other areas, which have no such connections, are called " association " or " silent " areas. Their nerve fibres connect one part of the cortex with another, thus enabling the different parts to work in harmony with each other. A significant point is that in the brain of animals the projection areas cover a larger proportion of the hemispheres than they do in the human brain. The difference indicates that in our mental activities the links between various parts of the cortex are of greater importance.

The picture we thus get reminds us of the brain-maps composed by phrenologists to indicate our " bumps " or regions connected with our various mental and emotional qualities. But while the phrenologist draws up his map mainly by ingenious guesswork and a fertile imagination, the brain physiologist, as we shall see presently, uses scientific methods to localize these special or "projection" areas.

One method is to make a post-mortem examination of injured brain. When a nerve has been cut it decays, and under the microscope the crumbling fibre is revealed by the use of a special stain. Thus, when the optic nerve connecting the retina of the eye with the brain has been severed, its track can be followed from the eye to the spot in the brain where it ends. By this process it has been found that each spot on the retina is linked with a group of cells at the back of the brain. To trace nerve tracks in this way is a tedious and difficult process, and the opportunities of applying it to various parts of the brain are not frequent, but it has enabled us to learn a good deal about how the pathways run from one part of the brain system to another.

The process is made a little simpler for the brain anatomist by the tendency of nerve fibres concerned with one kind of sensation to form bundles, which are much more easily identified under the microscope than are single fibres. Sensory nerves carrying messages concerned with touch, pain, heat, and so on from parts of the body reach the spinal cord in a kind of jumble; in

the cord, however, they arrange themselves in separate bundles which can be traced up to the brain and also (though with greater difficulty) to their termini inside the brain.

Another method of exploring the brain is to stimulate parts exposed during brain operations. If the stimulated part is associated with motor nerves, there will be a movement in the corresponding limb; if it is associated with sensory nerves there will be a sensation of some sort in the corresponding region of the body.

A curious feature of these experiments is that no sensation of pain is aroused when the cortex itself is stimulated. The part of the brain concerned with pain appears to be the *thalamus*—one of the central brain masses already mentioned. In the spinal cord the pain nerves are arranged in two bundles, one on each side, and they carry their messages directly to the nerve cells of the thalamus and no farther, while touch nerves can be traced right up to the cortex. Moreover, pain nerves produce a much smaller electrical effect when stimulated. Why the nerve mechanism of pain has these peculiarities is a problem which, like that of the purpose that pain serves in the lives of ourselves and other animals, is not yet wholly solved.

Although the exploration of the brain by these and other methods has still a long way to go before it is anything like complete, it has gone far enough to give us an outline of the brain structure and its mode of working. The main parts of structure have already been sketched,

and we shall now try to describe what happens to the stream of messages passing up the spinal cord and the brain stem.

The stream is a complex one, being made up of sensations of touch, sight, hearing, and so on. When it reaches the thalamus the several classes of sensation are sorted out and relayed to the appropriate parts of the cortex. Messages from the eye go to the special area at the back of the brain; those from the nose to the olfactory area at the base of each hemisphere, and so on. But their influence is not confined to the special areas; they spread through association fibres to other areas of the cortex, some of which are linked up with the central masses of grey matter, which in turn can influence the brain as a whole.

This intricate network of nerves can thus serve two purposes. It can separate the different sensory messages from a stream of impulses and register each in a particular part of the cortex, which is the seat of consciousness. It can also combine the cortical impressions in various ways. As Professor Le Gros Clark says, "It is one of the remarkable features of the cerebral cortex that it combines so efficiently the machinery for analysing incoming impulses, and also the machinery which permits their immediate interaction and integration." By machinery of this kind it becomes possible for us "to discriminate between one sensation and another, or to integrate sensations of various qualities so that we are able to form a mental impression of an object as a whole."

When we compare the human brain with the brains of animals nearly related to us, the difference in size is the first point that strikes us. As Sir Charles Sherrington says, "Ours is a monster brain." It is as big as the combined brains of two oxen. The second point is that the nerve mechanism is more intricate. Our larger cortex, with its profusion of nerve connections, gives us a far wider range of responses to sense impressions than any animal brain enjoys.

Thirdly, brain centres which in the animal were concerned only with automatic behaviour have, in the human brain, been promoted to the level of the cortex and now take charge, not merely of routine acts, but of behaviour which can be intelligently modified to suit changing circumstances. Professor Le Gros Clark gives an interesting example of this important step in evolution. If the visual section of a human cortex is destroyed, the man becomes totally and permanently blind. In the case of a rat similarly injured, however, its eyesight remains in such good working order that the animal can distinguish between different intensities of light and jump accurately from one platform to another. From this it might appear that rats are in a way better off than Man, but its true meaning is that in the rat the sensations of sight are dealt with, not by the cortex, but by lower brain centres; therefore the ways in which a rat can respond to visual impressions is quite restricted and virtually automatic. In Man, on the other hand, the transfer of the operating centres to the much more highly organized cortex makes

the range of his reactions to visual stimulus practically limitless, by introducing conscious control.

The advance from the animal brain to the human brain can, therefore, be expressed in several ways. It was an advance in the size and the complexity of the brain mechanism. It was an advance in specialization, and at the same time in the arrangements for close co-operation. It was an advance in what is called the "corticalization of brain function"—the transfer of control from lower brain centres to the cortex. This last change is regarded by Professor Le Gros Clark as not only an essential step towards the complicated mental processes that distinguish us from all other mammals, but also as providing the anatomical machinery that makes possible the conscious control of behaviour.

Our cerebral cortex, therefore, is the organ of the conscious control of behaviour. But while we must marvel at the capacities of that organ, at its ability to analyse our sensations, group them together, and select an appropriate course of action, we need not overlook the fact that its control is far from absolute. There are many things, as we have seen, that go on in our bodies over which the cortex has only a limited control or none at all. And the bodily system it is called upon to govern has inherited from its animal ancestors certain instincts and biological urges well adapted to aid the survival of animal species, but ill adapted to the novel and complex conditions which Man has created on his march from savagery to civilization. These instincts and urges are

rooted in the very depths of his being; they cannot be uprooted, and they are difficult to control.

The evolution of the human brain from the pre-human stage to its present monster size occupied a period variously estimated at from one million to several million years. Long enough, one might think, for Man to rise clear of his animal beginnings. But behind the period which saw the dawn of human reason lay the periods of hundreds of millions of years during which was shaped the basic structure of nerves and muscles and other organs which Man inherited from his animal ancestors.

It is a sobering thought that, judging by the evidence of fossil skulls, the size of the human brain has not increased to any appreciable extent within the last 200,000 years. As the beginning of civilization is dated at only five or six thousand years ago, it appears that Man, although equipped with much the same organ of conscious control as we enjoy today, took the best part of 200,000 years to get going as a civilized being. And each step in civilization involved a fresh struggle between new ways of life and old habits bequeathed by his animal ancestors. So difficult is it for him to adapt himself to such changes that the phrase, "every civilization creates its own evils" has become almost an axiom.

Some evolutionists offer the possibility that in course of time the human brain will improve so that its control over our emotional and instinctive inheritance will become really efficient. Others surmise that we shall

have to make do with our present equipment for all time. Whether we side with the optimists or the pessimists in this speculation does not affect our estimate of Man as he stands today. He may be a glorified animal, but he remains, by descent through vast ages, an animal.

CHAPTER IX

THE BODY-MIND PUZZLE

EVERYONE who thinks about nerves and brains and minds comes up against, sooner or later, the ancient puzzle over the relations between body and mind. How is our body, which is a material thing, connected with our thoughts and sensations, which are not material objects? And how, in turn, are our thoughts able to influence our bodily actions?

For centuries philosophers and men of science have been worrying over this puzzle without arriving at any agreed solution. Some of them bluntly assert that thoughts *are* material things and that the brain "secretes thought as the liver secretes bile." Others think that mental activity and brain activity are two quite different manifestations of energy, which somehow run in parallel with each other. Another school of thought holds that the mind is a separate spiritual something which expresses itself by means of the brain much as a musician expresses his soul by manipulating the strings of a violin.

Against all these notions stand the philosophers who suggest that we create the puzzle by separating mind and body as if they were distinct theatres of action. In a

thinking person something is happening which, examined in one way, reveals itself as electro-chemical activity in a network of nerves and, examined in another way, appears as thought and feeling.

When doctors disagree, the ordinary man can do no more than suspend judgment on theories and confine himself to what is actually *known* on the subject. We at least know, from a multitude of undisputed facts, that the relationship between brain and mind is extraordinarily close. Many of the facts can be gleaned from our own experiences of how illnesses, by affecting the blood supply to our brain, can cause depression and mental lassitude: and how, in reverse, the tone of our body can be improved by the communication of cheerful thoughts. The records of brain surgery are rich in more dramatic evidence. A tumour pressing on the brain can produce abnormal mental conditions which disappear when the tumour is removed. One of the after-effects of sleepy-sickness is extreme mental irritability, with a tendency to violent action; this can be cured by cutting bundles of nerves connecting the front part of the brain (which is intimately concerned with the control of emotion) with the rest. A similar operation can relieve mental patients of the acute anxieties that obsess them. Memory remains, and there is no interference with sensory perception or motor control, since these are taken care of by other sections of the brain; there is, however, some loss in the power of initiative, and there are other possible drawbacks which make a cautious brain surgeon weigh up the

advantages and disadvantages before he performs the operation.

Operations of this kind have led some people to imagine that by brain surgery we might so alter a man's intelligence or character as to make a new man of him. Professor Geoffrey Jefferson, who has performed scores of such operations, considers this notion as "fantastically untrue." "The one great lesson that runs through all my experiences of brain surgery," he says, "is that however much a person is changed by disease or injury of his brain he is never changed into somebody else but only into some modification of himself." This view can be the more readily accepted if we bear in mind that all our nerves cells are in position when we are born; that is to say, the basic mechanism of our intelligence and emotional character is complete at birth.

On the other hand it is a fact that disease and injury of the brain can have a profound effect on behaviour. For example, as an after-effect of epidemic encephalitis (inflammation of the brain) individuals may lose their sense of social responsibility and of right and wrong. Such cases raise interesting questions about our attitude to crime and delinquency, but for our present purpose they are useful as underlining the intimate relation between mind and body. As Professor Jefferson puts it: "The body provides the energy for its nerve cells, which do in fact make great demands on the body's chemistry. Cut out vitamin A and our retinal cones will not act, we are night blind; cut off our thyroid

hormones and our mental powers flag and fail to the point of dementia; deprive us of nicotinic acid and the same sort of mental consequences happens; cut off our oxygen and it is the brain that dies first and that in less than ten minutes. Similarly, brain is sensitive to body's toxins, as we see in the coma and convulsions of uræmia or in the delirium of infections such as pneumonia. Its sensitiveness to extraneous poisons such as alcohol is famous."

With the invention of the electroencephalograph (familiarly known as EEG.) it has become possible to

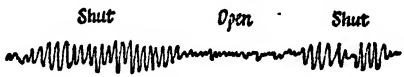


FIG. 19.—A human electroencephalogram, showing the alpha rhythm when the eyes are open and shut.

record, in some degree, the working of a brain, much as we might record the working of an enclosed machine. Electrodes are placed at various parts of the skull and the varying electrical potentials in the different regions are amplified and translated into wavy lines on a moving chart. From the rhythmic form of these lines the condition, abnormal or normal, of regions of the brain can be inferred.

When the EEG. is applied to a patient lying quietly with his eyes shut, a line on the chart shows fairly regular waves at the rate of about ten per second. This is called the "alpha" rhythm. If the patient is asked to open his eyes or do a sum in mental arithmetic, or if he is startled

by a sudden noise, the alpha rhythm disappears. A similar rhythm is recorded from the brain of an animal under the influence of a narcotic. Thus it indicates a sort of resting or mark-time condition of the brain cells concerned. As soon as the brain is called to attention, the chart records the change.

The interpretation of the alpha and other rhythms recorded by the EEG. when applied to healthy and unhealthy brains is a highly technical branch of the new science of neurology—the study of nerves. What concerns us here is that the technique, which has already aided the diagnosis and treatment of mental illnesses, takes no account of a possible little cherub sitting aloft in a control tower and manipulating the nerve cells of the brain. To the neurologist the brain is an organ to be studied, in structure and function, just as the stomach or the liver is to the physiologist.

Nevertheless, it is difficult for us to get rid altogether of the idea of a little cherub. The habit of mind induced by the old-established doctrine that Man is a compound of body, soul, and spirit is very tenacious, even among people who substitute the word "mind" for "soul" and "spirit." In this connection Professor Gilbert Ryle relates in his *The Physical Basis of Mind* a story of some peasants who, being terrified at their first sight of a railway train, were told by their pastor how a steam-engine worked. One of the peasants said he quite understood about the steam-engine, but he added: "But there is really a horse inside, isn't there?"

To this story Professor Ryle adds an invented sequel. Having examined the engine inside and out, and having failed to see, hear, or feel a horse, the peasants maintained that as they knew there *was* a horse, "it must be a ghost-horse which, like fairies, hides from mortal eyes." When the pastor pointed out that, as horses themselves were made of moving parts, there was no more mystery in a self-propelled engine than in a horse, and then followed with the question, "What do you think makes the horse's hooves go to and fro?" the answer he got was "four extra little ghost-horses inside."

One of the reasons why the ghost-idea still haunts us when we are thinking of the human mind is that the alternative seems to be that Man is a "mere machine." But are we justified in applying to any living organism a word used to define a different order of existence? A machine is a contrivance designed and made by man to do certain things; a living organism is composed of highly elaborate molecules which confer upon it the ability to absorb food, to grow, to reproduce. There are, of course, certain resemblances between the two; both move, utilize energy, convert it from one form to another, and so on. But it is an abuse of language to insist that unless we regard a living organism as charged with some mysterious influence that eludes the grasp of Science we must reduce it to the ranks of mechanical engineering.

Ironically enough, recent triumphs in the world of machines have induced people to look with a more

searching eye at the differences as well as the likenesses between machines and living things. The electric calculating-machine, which contains about 10,000 valves and is capable of solving the most elabrate arithmetical problems in "next to no time," has been dignified with the title of the "electronic brain." Machines of this kind remind us in more than one way of our own mental operations. They are self-organizing, in the sense that with each new item of experience they reach a new state of equilibrium. They, in common with automatic steering-gear and automatic aircraft-piloting, embody a principle known as "negative feed-back" which resembles the automatic processes of temperature control in our bodies. By being capable of electrically storing the effect of each previous stage of an operation as they go along, they may claim a kind of memory; there is a parallel here between the operation of linked relays in the machine and that of nerve cells in the brain, though the machine clears itself of all "memories" when its task is completed, while the nerve cells do not.

How far the development of such machines will carry us it is, of course, impossible to say. Enthusiasts speak of brain-machines which will perceive, learn, adjust their own controls, and do various other things analogous to the mental operations. Yet, however closely an artificial brain may simulate the natural brain, and however much it may excel the brain in calculating, predicting, and other operations, it remains an electro-mechanical contrivance with the limitations imposed by

its materials and structure. In Professor D. R. Hartree's words: "Given a schedule of instructions, all a machine can do is to follow it exactly, and this remains true even though the schedule includes selection between alternative procedures in the course of the calculation. For this reason the term 'electronic brain' which has been applied to these machines, seems unfortunate and misleading; it might be taken to imply that they can 'think for themselves,' which is just what they cannot do; all they can do is to follow blindly and unthinkingly the schedules of instructions which have been thought up for them."

The moral to be drawn from the remarkable imitative performance of the so-called electronic brain is that our mental processes are not, as we used to think they were, absolutely unique. Kinship between Man and the rest of living things has been admitted for some time; now we may feel inclined to broaden the sense of relationship to the inanimate world from which life itself emerged. The aphorism that "all Nature is one" becomes an axiom when we remember that Man, animals, plants, micro-organisms, and viruses are constructed of the same atomic materials as earth, sun, and nebulæ, and that the atoms are variations of a fundamental electronic theme.

Curiously enough, certain machines which are as remarkable for their simplicity as the electronic brain is for its complexity have a bearing on this idea of the oneness of Nature. Dr. W. Grey Walter and his colleagues at the Burden Neurological Institute, Bristol,

have amused (and edified) themselves by constructing small machines, resembling toy tortoises, with photo-electric cells and other automatic services to control their movements. The behaviour of these toys is wonderfully lifelike and their responses to changes in their surroundings are not predictable. Indeed, they give a quaint suggestion of having a will of their own and, on occasion, of being " temperamental."

The equipment of these electro-mechanical " animals " is extraordinarily simple. It consists of two miniature electronic valves, two relays, two condensers, two miniature electric motors, two batteries, and two " receptors." One of the receptors is a photo-electric cell, which gives responses to light; the other is a touch receptor—a sensitive electrical contact which acts when the animal meets an obstacle. This equipment corresponds to only two nerve cells, yet it provides an astonishingly varied performance when the machine, with its batteries charged, is allowed to roam about a room.

The photo-electric cell scans the surroundings by sweeping steadily round and round, and when it meets a light of moderate intensity it stops rotating and the machine moves towards the light. (" A similar relation between sensory and motor systems is," remarks Dr. Grey Walter, in *Discovery* for March, 1950, " believed to exist in the brain.") Bright lights, however, repel the machine. When an obstacle is met, the machine alternately butts the obstacle and withdraws, so that it either pushes the obstacle out of the way or (in the case of a

heavy object) goes round it. This action is due to making any slight displacement of the shell of the machine convert the photo amplifier into an oscillator; at the same moment the "pull" of the light towards which the machine was moving ceases to have any effect, remaining without any effect until the obstacle has been cleared. After the machine has got free again, a second or so passes before the scanning for an attractive light is resumed—much as if the mechanism had a "memory" of the conflict.

In the head of the machine there is a small flash lamp which is switched off when the photo-electric cell receives an adequate light signal. Amusing results follow when the machine, attracted by the reflection of its headlight, approaches a mirror. As it draws near, the intensity of the reflected light leads to the automatic switching off of the headlight, thus removing the attraction. In Dr. Grey Walter's words: "The creature therefore lingers before a mirror, flickering and jigging like a clumsy Narcissus." And he adds that if such behaviour were observed in an animal it "might be accepted as evidence of some degree of self-awareness."

When the batteries of the machine need replenishing, a light on a recharging "hutch" is used to attract the machine. As run-down batteries make the machine less sensitive to strong light, the machine is not repelled when it is close to the hutch but goes straight in. At the moment of contact the battery-charging circuit is closed and the motors and photo-electric cells in the machine are

cut out; the machine remains motionless until it is fully charged again.

More elaborate models, with devices to mimic the processes of learning, mutual aid, and social behaviour have been devised, but Dr. Grey Walter emphasizes that the models described suggest that "an anatomical circuit containing only two elements is enough to provide behaviour patterns of unpredictable complexity."

With the behaviour of these little machines in our minds we can begin to realise the difficulty, if not the impossibility, of predicting the behaviour of the brain, even if it were treated as "a mere machine." Although it is quite true, as Professor Geoffrey Jefferson reminds us, that "many of our thoughts, our decisions, our actions, are much more predetermined than we imagine," and that "that fine set of prejudices, our opinions, are largely the fixed ideas that our brains trot out when the given stimulus is applied," the brain, with its millions of nerve cells, its intricate structures, its stores of memories and emotions, is so complex that when we have to make a choice between several evenly balanced possibles, "chance might be the final arbiter." So the old question whether Man enjoys "free will" or whether his actions are "determined" is seen in a new light. Professor Jefferson, for example, does not think that "free will" has much meaning for the physiologist, who does not picture our elaborate brain as rigidly automatic: "Man's range of choice is so varied, and the personal history that influences his decisions not only so colourful, but its

ingredients are so plastic and of such changeable weight, that there are enough variables to make 'will' to all intents and purposes 'free'."

To return to the body-mind puzzle, it is not suggested that by exorcising the "ghost" in the brain we have removed the sense of mystery inspired by the human mind. That a series of electro-chemical changes in a network of nerves should be accompanied by mental pictures which can be compared and grouped, and stored in our memory, and reasoned about, is in itself a marvel of the first degree. Nevertheless, there is a sense in which this crowning achievement of five hundred million years of the evolution of life is no more marvellous than the least of the things so simple and so familiar that we take them for granted and imagine that we "know all about them."

Every schoolboy, for instance, learns that when two parts of hydrogen and one of oxygen are combined they form water. But in how many of these boys—or of their teachers, for that matter—does this elementary fact inspire the faintest feeling of wonder? How can we explain the emergence from two substances, each with its own special properties, of a third substance with quite a different set of properties?

A certain amount of light is thrown on problems of this sort by our knowledge of the electronic make-up of the atoms concerned. We have learned a good deal about the electrical changes that take place when various atoms unite to form molecules, and we can correlate the be-

haviour of substances with the way in which their molecules are arranged. But this carries us no farther than the corresponding knowledge that the behaviour of our minds is correlated with the arrangement of our nervous system. For the chemist and the physicist there remains the mystery of the nature of the electrical particles and of how they contrive, by their interaction, to produce such a variety of manifestations. And if we consider this ultimate mystery to be beyond our reach, and that we must be content merely to relate the behaviour of "dead" substances to their internal structure, we may extend the same principle to substances that are alive and form the "physical basis of mind."

In this connection it is interesting to trace the change that has taken place in our attitude towards a puzzle which used to worry philosophers as much as the body-mind puzzle does today. For centuries living matter was regarded as absolutely distinct from non-living matter; it was dust upon which the creator had breathed a unique property. To a sixteenth-century physician like Jean Fernel (as shown in Sir Charles Sherrington's *Life's Unfolding*) the living body did not work itself; it was tenanted by a principle that made it "live," something immaterial that used the body as a craftsman uses a tool.

In other words, the body had the same sort of "ghost" as the mind is still supposed to possess. The mystery of life was "explained" by invoking an unknown quantity and giving it a name. Not until the nineteenth

century, when the idea of evolution as a universal principle became familiar, was this particular ghost's tenancy seriously threatened. Suggestions were made that living matter might have developed naturally from non-living matter, and, as we saw in an early chapter, more than one experimenter tried to make protoplasm in the laboratory.

The failure of these experiments did not disturb the trend of thought in favour of treating living matter in precisely the same scientific way as non-living matter. It did, however, give some encouragement to the "vitalists" who still, as Fernel did in the days before Galileo, insist upon calling in aid a mysterious "vital principle," which some of them dignify with the name of "entelechy," defined as "a supposed vital or purposive principle guiding and controlling organisms and their evolution."

With the rapid advances in biochemistry—the science of life—vitalism is becoming an intellectual curiosity. Today it would be impossible to revive, even in a mild form, the bitter controversies that raged in the nineteenth century over the alleged gulf between life and not-life. When they were in full blast, the vitalists accused their opponents—the mechanists—of degrading organisms to the level of "mere machines;" the mechanists, on their side, accused the vitalists of offering a meaningless word as a solution of the problem of life. The last echoes of their battles have died away; the animate and the inanimate are now separated only as one branch of science is separated from another.

A certain mental effort, in fact, is needed to realize that the life-matter relationship was once looked upon as being just as mysterious as the mind–body relationship is today.

Consciousness presents us with a similar sort of puzzle, with complexities of its own. It is an accompaniment of mental activity in the higher ranks of brain development, but it is an elusive phenomenon whether one studies one's own consciousness or seeks evidence of consciousness in other animals. There was a time when the sense of mystery surrounding it so impressed the mind of Man that a special creative act was invoked to "explain" it. Lloyd Morgan declined to define consciousness, because any definition would involve a direct reference to primary experience; so he assumed that his readers were conscious and knew what he meant when he said that they were conscious. After examining what went on in his own conscious mind he represented consciousness as a wave with a crest of clear awareness and slopes of dimmer consciousness on all sides.

This picture does at least illustrate the mobile and complex qualities of consciousness, which make measurement difficult. And when we try to gauge the state of consciousness of other people, we encounter such anomalies as the immobile "unconscious" sleeper who is yet conscious of dreaming and may remember his dream on awaking, and the sleep-walker who walks and talks yet is unconscious. The difficulties are increased in the case of animals, as there we cannot safely check our

observations by reference to our own inner experience, since we are not dealing with strictly comparable brains.

All these uncertainties do not, however, imply that consciousness is another and rather irresponsible "ghost." They will be seen to belong to the natural order of things when we examine consciousness from the evolutionary standpoint we have adopted in studying the birth and growth of nerve systems.

It is impossible to run one's eye up the ladder of life and point to a particular level as marking the dawn of consciousness. We are safe in saying that lowly organisms like amœba and Convoluta lead unconscious lives, that animals with a ring of nerves, like the jellyfish, are also without consciousness, and that worms, with their ganglions operating ladders of nerves, are still in mental darkness. But when we touch the level of insects, we may hesitate. Can we deny to ants and bees, which appear so "intelligent," at least a glimmer of consciousness? The answer suggested by the structure of their nerve systems is that we probably must, since these systems are merely nerve systems admirably adapted to respond automatically to various stimuli.

Fish, which represent a still higher level, are yet doubtful claimants, as their nerve organization, though more elaborate than that of insects, is mainly on the reflex model. We have no compunction in netting and destroying fish by the million, and fishing is one of the more civilized sports: two facts which rouse no emotions in animal-protection societies. It is not until we reach the

reptile and bird stages that we really look for the dawn of consciousness, and it is by the progressive development of the cerebral hemispheres that we measure the degrees of increasing illumination. In Man we find the highest elaboration of conscious life—self-consciousness. In the human individual there is a similar slow emergence of consciousness from darkness through twilight. The embryo growing in the womb is unconscious; consciousness begins with the crisis of birth, when the activity of the infant brain is stimulated by sight, sound, taste, and touch. For the first few years the behaviour of the child is mainly on an instinctive level and is subject to parental discipline. The impressions of pain or pleasure received by the child in the process of training are acutely felt, as one can see from the child's reactions, but for the most part they do not survive in the conscious memory. Few of us can remember anything that happened before we reached the age of three or four years, and our earliest recollections usually are of some event which made a particularly deep impression—rousing not so much awareness of the event itself but of ourselves as observers of the event. That is to say, it awakened self-consciousness. Other events sink into the subconscious and become part, as it were, of our instinctive life, influencing our behaviour in adult life without our being aware of their existence.

The development of consciousness in the individual thus mirrors the development in the evolution of Man.

Bearing in mind that the final stages in this process—

from the anthropoid type of brain to the "monster" human type—were rapid compared with the growth of the nerve system through vast geological ages, it is clear that Man's higher faculties are a kind of late addendum to a brain and nerve system largely concerned with unconscious life. The conception of a subconscious mind, shaped by influences reaching back through scores of millions of years of animal evolution, and allied with a conscious mind of more recent descent, was familiar to comparative psychologists before Freud made it the germ of his psychological theory and practice. The conscious and the subconscious are, of course, not two minds, since the cerebral hemispheres are, like other regions of the brain, an outgrowth of the central nervous system, and all parts are in intimate intercommunication. There is constant two-way traffic between the conscious and subconscious regions (as we well know when we fail to remember a name when we "think hard" and suddenly find it given to us by a chance association which has lifted it from the subconscious level).

The importance now attached to what goes on below the level of consciousness, in what we may call the ancestral parts of our nervous system, endorses the principle that the clues to the riddles of Man's nature are to be found in Man's past. The proper study of Man, therefore, is the study of Man's evolution. Our essay, in this little book, has been confined to one aspect of the subject—the organ mechanism of control. It may, however, serve to bring home the soundness of the view

expressed in Alfred Machin's *What is Man?* "Man, too, is understandable. There is reason for all that he is and for all that he does. All we have to do is to disentangle the threads of our ancestry, to see the operation of the natural selection of the fittest, and we can understand why we are what we are."

LIST OF USEFUL BOOKS

Plant-Animals. By Frederick Keeble, Sc.D. (Cambridge University Press, 1910.)

Life's Unfolding. By Sir Charles Sherrington, O.M. (Watts.)

An Introduction to Comparative Psychology. By C. Lloyd Morgan. (Walter Scott, Ltd.)

The Matrix of Mind. By Professors F. Wood-Jones and S. D. Porteous. (Edward Arnold.)

The Stuff We're Made Of. By W. O. Kermack, D.Sc. and P. Eggleton, D.Sc.

Living Machinery. By Professor A. V. Hill, D.Sc., F.R.S. (Bell.)

The Physical Basis of Mind. A series of Broadcast Talks. (Basil Blackwell.)

The Physical Background of Perception. By E. D. Adrian, O.M., F.R.S. (Oxford University Press.)

The Basis of Sensation. By E. D. Adrian. (Christophers.)

Neurological Foundations of Animal Behaviour. By Professor C. Judson Herrick. (Henry Holt: New York.)

61. MAN AND HIS UNIVERSE *by* John Langdon-Davies

The story of man's attempt to solve the mystery of creation.

62. FIRST PRINCIPLES *by* Herbert Spencer

A scheme of belief which meets the need of the modern mind for a clear and orderly synthesis of knowledge.

63. RIGHTS OF MAN *by* Thomas Paine

A great text-book of Democracy and democratic ideals.

64. THIS HUMAN NATURE *by* Charles Duff

Wise, witty, and entertaining. A survey of the development of human nature through the ages.

118. FRIAR'S LANTERN *by* Dr. G. G. Coulton

A fantasy in which the adventures of two modern pilgrims, transported by magic to the Middle Ages, are recounted with ironical humour.

119. IDEALS AND ILLUSIONS *by* L. Susan Stebbing

Criticizes some popular ideals and outlines those which, in the author's view, should guide and inspire our zeal for progress.

120. AN OUTLINE OF THE DEVELOPMENT OF SCIENCE (Illus.) *by* Mansel Davies

An account of the long, arduous, and often dramatic search into Nature's secrets.

130. THE MYSTERY OF ANNA BERGER *by* George Godwin

The moving story of an Austrian peasant girl who suffered that amazing phenomenon—the stigmata of Christ.

131. WRESTLING JACOB *by* Marjorie Bowen

A fascinating biography of John Wesley, written with unusual candour and objectivity.

133. THE HERO *by* Lord Raglan

The author concludes that all the great heroes of myth and legend began as ritual characters.

134. THE LIFE OF JOHN KNOX *by* Marjorie Bowen

A biography of one of the most remarkable and fiercely debated figures in Scottish history.

135. THE FRENCH REVOLUTION *by* Archibald Robertson

The thrilling story is here retold with a special bearing on the familiar fallacy that the Church has always been the chief custodian of the rights of man.

136. THE ART OF THOUGHT *by* Graham Wallas

An authoritative exposition of the process of reasoning.

139. THE SCIENCE OF HEREDITY (Illus.) *by* J. S. D. Bacon

Explains the production of new varieties of plants and animals and the impact of genetics on the life of man.

140. THE GREAT REVIVALISTS *by* George Godwin

Contests the view that religious revivals can be accounted for only by supernatural causes.

Bound in clothette, each 2s. 6d. net

4. HUMANITY'S GAIN FROM UNBELIEF *by* Charles Bradlaugh

A typical selection of the most vigorous and interesting writings of the great leader of Freethought.

5. ON LIBERTY *by* J. S. Mill

A great classic of political science and philosophy which should be read by all who value freedom.

7. AUTOBIOGRAPHY OF CHARLES DARWIN

Includes Sir Francis Darwin's reminiscences of his father's everyday life and concludes with a statement of Darwin's religious beliefs.

12. THE DESCENT OF MAN *by* Charles Darwin

Darwin marshals the overwhelming evidence for a common origin of man and animals.

14–15. ANTHROPOLOGY (2 vols., Illus.) *by* Sir E. B. Tylor, Kt.

Describes in easy and graphic style the origins of language, arts, customs, and religious ideas in primitive societies.

29. IN THE BEGINNING: THE ORIGIN OF CIVILIZATION (Illus.) *by* Prof. Sir G. Elliot Smith

Discusses the origin of many human customs and institutions and also the world-wide diffusion of culture in the remote past.

32. ON COMPROMISE *by* John Viscount Morley, O.M., P.C.

A classic on the eternal problem of human integrity.

33. A HISTORY OF THE TAXES ON KNOWLEDGE *by* Collet Dobson Collet

The vivid story of the long struggle for the freedom of the Press.

35. THE STORY OF THE BIBLE *by* Macleod Yearsley

A survey of the origin and growth of the Bible in the light of modern knowledge.

41. FIRESIDE SCIENCE *by* Sir E. Ray Lankester

The articles here selected, which deal with a variety of scientific problems, show the author at his best.

42. HISTORY OF ANTHROPOLOGY *by* Dr. A. C. Haddon

A record of the steps by which our knowledge of primitive races and customs has been built up.

46. THE MIND IN THE MAKING *by* James Harvey Robinson

Shows how mankind may plan to save civilization from the menace of war and of moral and economic confusion.

47. THE EXPRESSION OF THE EMOTIONS IN MAN AND ANIMALS (Illus.) *by* Charles Darwin

Brims over with testimony of the kinship between man and animals.

48. PSYCHOLOGY FOR EVERYMAN (AND WOMAN) *by* A. E. Mander

An explanation of the everyday behaviour of men and women and of the ways in which mental difficulties may be avoided.

52. FIVE STAGES OF GREEK RELIGION *by* Prof. Gilbert Murray, O.M.

Five essays dealing with the complex evolution of religious ideas in ancient Greece.

53. THE LIFE OF JESUS *by* Ernest Renan

Renan's famous work on the foundation of Christianity was the first to present Jesus as an entirely human figure.

54. SELECTED WORKS OF VOLTAIRE *trans. by* Joseph McCabe

These selections from the thirty volumes of Voltaire illustrate his masterly faculty for wit and irony.

57. CLEARER THINKING: LOGIC FOR EVERYMAN *by* A. E. Mander

A book for all who wish to master the skill of thinking clearly and accurately.

59. YOUR BODY: HOW IT IS BUILT AND HOW IT WORKS (Illus.) *by* Dr. D. Stark Murray

An introduction to human physiology and anatomy, giving simple descriptions, with illustrations, of the organs of the human body.

66. A BOOK OF GOOD FAITH: SELECTIONS FROM THE WORKS OF MONTAIGNE *edited by* Gerald Bullett

This volume, by its diversity of subject and mood, reflects the incomparable richness and liberality of Montaigne's mind.

67. THE UNIVERSE OF SCIENCE *by* Prof. H. Levy

A critical examination of the philosophy of Jeans and Eddington, and an exposition of the scientific method.

69. THE AGE OF REASON *by* Thomas Paine

A penetrating criticism of Christianity from a "common-sense" point of view.

72. A SHORT HISTORY OF WOMEN *by* John Langdon-Davies

Discusses the customs and practices which have governed the position of women from earliest times to the present day.

74. MORALS, MANNERS, AND MEN *by* Havelock Ellis

An anthology of reflections on eugenics, war, and other social problems by a writer famous in the worlds of science and literature.

78. THE MAN VERSUS THE STATE *by* Herbert Spencer

A classic statement of the case for individual liberty.

79. THE WORLD AS I SEE IT *by* Albert Einstein

Einstein's considered views on many religious and other topics of vital importance.

81. THE TWILIGHT OF THE GODS *by* Richard Garnett

A delightful blend of learning and laughter.

83. RELIGION WITHOUT REVELATION *by* Julian S. Huxley

Shows that a progressive religion can be constructed on lines that appeal to the modern intellect, without belief in the supernatural.

84. LET THE PEOPLE THINK *by* Bertrand Russell, O.M.

A message for the world, revealing the essential way towards a "new order" of sanity and stable civilization.

86. THE LIBERTY OF MAN, AND OTHER ESSAYS *by* R. G. Ingersoll

This glowing appeal for a full measure of human freedom carries a vital message to the world today.

87. MAN MAKES HIMSELF *by* Prof. V. Gordon Childe

An authoritative account of the way in which early man strove to obtain mastery over his environment.

89. THE ORIGIN OF THE KISS, AND OTHER SCIENTIFIC DIVERSIONS *by* C. M. Beadnell, C.B., F.Z.S.

Combines instruction with entertainment and reveals many quaint and fascinating phases of natural science.

90–91. THE BIBLE AND ITS BACKGROUND (2 vols.) *by* Archibald Robertson
A lucid account of the conditions under which the various Books of the Bible were produced.

93. THE GOSPEL OF RATIONALISM *by* C. T. Gorham
The reader in search of a credible religion will find this book a stimulating introduction to the essential meaning of Rationalism.

94. LIFE'S UNFOLDING *by* Sir Charles Sherrington, O.M.
A fascinating yet factual picture of the evolution of life from the unicellar organism to its highest manifestation in man.

95. AN EASY OUTLINE OF ASTRONOMY (Illus.) *by* M. Davidson, D.Sc., F.R.A.S.
An exposition of the main facts of astronomy for readers who have little or no acquaintance with the subject.

97. MAN STUDIES LIFE *by* G. N. Ridley
The story of the progress of biological thought and discovery from Hippocrates to the present time.

98. IN SEARCH OF THE REAL BIBLE *by* A. D. Howell Smith
An analysis of the Books of the Bible in the light of the latest research into their composition and history.

99. THE OUTLINES OF MYTHOLOGY *by* Lewis Spence
A popular description of the general principles of mythology.

100. MAGIC AND RELIGION *by* Sir J. G. Frazer, O.M.
The essence of Frazer's teaching on the development of religion and its relation with primitive magic.

101. FLIGHT FROM CONFLICT *by* Sir Laurence Collier
A survey of the foundations of morality, exposing the fallacies of the mystical and quietist school.

102. PROGRESS AND ARCHÆOLOGY *by* Prof. V. Gordon Childe
The problem of human progress is scientifically studied by surveying the progressive tendencies of mankind during the last 50,000 years.

103. THE CHEMISTRY OF LIFE: AN EASY OUTLINE OF BIOCHEMISTRY *by* J. S. D. Bacon
An introduction to Biochemistry, which deals with living processes as chemical transformations and explains life in exact terms.

104. MEDICINE AND MANKIND (Illus.) *by* Dr. A. Sorsby
An account of the meaning and mechanism of disease in which medicine is visualized as a living force in a changing world.

106. THE GREAT MYSTICS *by* George Godwin

A study of mysticism, in which the author examines the lives and personalities of famous mystics from St. Paul to William Blake.

108. GEOLOGY IN THE LIFE OF MAN *by* Duncan Leitch

An easy guide to the study of the geological agencies at work in shaping the history of mankind.

110. JESUS: MYTH OR HISTORY? *by* Archibald Robertson

A balanced statement of the main arguments on the question whether Jesus was a historical or a purely mythical character.

111. THE ETHICS OF BELIEF *by* W. K. Clifford

Deals with right thinking and right action, and will be of absorbing interest to all students of scientific and religious questions.

112. HUMAN NATURE, WAR, AND SOCIETY *by* Dr. John Cohen

A study of the nature and the possible control of the fundamental factors—psychological, sociological, and economic—that make for recurrent war.

113. THE RATIONAL GOOD *by* L. T. Hobhouse

Hobhouse's masterly exposition of a system of ethics based solely on rational grounds.

114. MAN: THE VERDICT OF SCIENCE *by* G. N. Ridley

An assessment of man, including the anatomical and physiological characteristics of his body, mental activities, and social habits.

115. THE DISTRESSED MIND *by* J. A. C. Brown, M.B., Ch.B.

Gives sound, practical advice on difficulties which handicap the well-being of everybody.

116. THE ILLUSION OF NATIONAL CHARACTER *by* Hamilton Fyfe

A searching examination of the current notion that the human family is divided into "nations" and "races," each with distinct physical, mental, and moral characteristics.

117. POPULATION, PSYCHOLOGY, AND PEACE *by* Dr. J. C. Flugel

A frank and arresting discussion of population problems.

121. HEAD AND HAND IN ANCIENT GREECE *by* Prof. B. Farrington

A provocative study of Greek activities in the sphere of contemplative science and philosophy, the arts of production and construction, and in the field of practical medicine.